Gilbert Cady

INTERNATIONAL GEOLOGICAL CONGRESS

REPORT OF THE EIGHTEENTH SESSION
GREAT BRITAIN 1948

PART VIII (7)

PROCEEDINGS OF SECTION G

THE GEOLOGY OF SEA AND OCEAN FLOORS

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General Editor: A. J. Butler

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THE GEOLOGY OF SEA AND OCEAN FLOORS

Edited by

W. B. HARLAND and O. T. JONES

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Section G, The Geology of Sea and Ocean Floors, met on two occasions during the Session. The successive Chairmen at these meetings were as follows :-

August 27th	**Professor O. T. Jones**
	Dr. J. S. Lee
August 30th	**Professor Dr. J. H. F. Umbgrove**
	Dr. R. M. Field

The Secretary of the Section was Mr. W. B. Harland.

Printed by Co-operative Wholesale Society Ltd.,
Reddish, Stockport.

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RÉSULTATS GÉNÉRAUX DES DERNIÈRES ÉTUDES OCÉANOGRAPHIQUES SUR LE PLATEAU CONTINENTAL FRANÇAIS

Par JACQUES BOURCART

France

RÉSUMÉ

Pendant la dernière décade, l'équipe que je dirige a entrepris divers travaux sur la sédimentation le long du littoral français. Les résultats ont été brièvement résumés lors de la réunion belgo-hollando-française de Gand. Après la fin des hostilités, une étroite collaboration avec la Marine Nationale nous a permis d'étendre ces recherches aux diverses régions du Plateau continental français, le plus souvent délaissées par les océanographes. Bien qu'encore très incomplètes, elles feront l'objet d'un prochain Mémoire. Je voudrais, dans ce court exposé, en donner connaissance de l'essentiel au Congrès, surtout pour provoquer critiques et suggestions de la part de nos confrères. Enfin, j'ai été amené, pour expliquer bien des faits que j'avais observés le long du littoral et qui semblent difficiles à interpréter par l'hypothèse de variations purement *eustatiques* du niveau des mers, si généralement acceptée aujourd'hui, de proposer celle d'une déformation crustale, variable dans le temps et dans l'espace, des terres émergées et du fond des mers en général. Cette hypothèse, dite de la "flexure continentale," n'a pas été prise en considération, à l'exception du récent ouvrage d'Umbgrove: *The Pulse of the Earth.* Il m'a semblé utile, à la fin de cet exposé, de présenter les principaux arguments qui font que je lui garde actuellement encore créance.

I. GÉOLOGIE DU PLATEAU CONTINENTAL FRANÇAIS

TOUS les dragages effectués par le trois-mâts *Pourquoi Pas?* et le vapeur océanographique *Président Théodore Tissier* avant la guerre, ont montré que le Plateau continental français était (à l'exception de bancs ou d'îles en situation *anticlinale*) fait de Crétacé ou d'Eocène, ou de terrains plus récents. L'un et l'autre de ces deux premiers terrains ont été mis en évidence, grâce à de gros blocs dragués (Louis Dangeard), mais le second avait été trouvé en place, notamment dans la région de Lorient. Du Miocène avait été également signalé. Depuis la guerre, j'ai découvert, sur le littoral breton de la Manche (Roscoff), le Turonien *en place*; il ne présente pas de facies littoral et a pu donc recouvrir tout ou partie du Massif armoricain, aujourd' hui bombé en anticlinal. Si, comme le pensait Paul Lemoine, la Manche, qui fait intégralement partie du Plateau continental, est un synclinal de terrains mésozoïques, celui-ci semble se poursuivre tout le long de l'Atlantique français (couches secondaires et tertiaires), le pendage se faisant toujours *vers le large.* Cette disposition est la même que celle que Maurice Ewing déduisait des sondages sismiques faits au large de Cape Henry (Virginia) et que E. C. Bullard et T. F. Gaskell ont obtenue, par la même méthode, au large du Cap Lizard: 4.000 mètres de sédiments secondaires et tertiaires auraient été reconnus sous le Plateau continental américain.

En Méditerranée, dans deux cas, nos dragages ont réussi à fournir des documents utilisables pour l'établissement de la stratigraphie du Plateau, dans deux cañons sous-marins qui permettent seulement de faire, comme disent les géologues, une coupe: dans le "rech Lacaze Duthiers" et dans le cañon de la Cassidagne, entre Marseille et Toulon. Des blocs, grâce à une technique très simple, ont été arrachés des parois de ces "vallées submergées." Dans le premier cas, au large des Albères (extrémité orientale de la chaîne des Pyrénées, qui sont du Cambro-Silurien), du Vindobonien fossilifère, à facies italien, a été dragué; dans le second, où la côte est turonienne (synclinal du Beausset), au lieu de trouver de l'Urgonien ou du Crétacé inférieur, nous avons arraché des phyllades siluriennes qui ne peuvent appartenir qu'à un prolongement sous-marin de la "Nappe de Sicié" d'Emile Haug conservé en synclinal

de nappe. La méthode, dont la technique est actuellement bien fixée, peut permettre, en opérant dans les 17 cañons sous-marins du Golfe du Lion, de dresser de véritables coupes géologiques qui, au moins, seront inattendues.

Tous les dragages sous-marins qui ont été effectués par nous sur le Plateau continental atlantique du Maroc, ont ramené du Pliocène, soit côtier (fonds de 500 mètres), soit littoral (fonds de 100 mètres). Il s'agit, vraisemblablement de dépôts d'un stade dans la grande régression de la fin de cette époque (Villafranchien, *sive* Calabrien des auteurs).

On peut donc admettre dans ce cas, en première analyse que, même si le Continent est fait de Paléozoïque ou d'Antépaléozoïque, le Plateau continental est formé de couches secondaires et tertiaires, d'autant plus récentes que l'on va vers le large, et pendant toutes vers la mer. Il faut rappeler ici que Hans Pettersson a dragué, au large d'Alger, entre 2.300 m. et 2.700 m., des sables grossiers quartzeux et des pouzzolanes volcaniques, littorales ou continentales. Un subsidence considérable, si ces observations sont correctement interprétées, devrait avoir eu lieu, à la fin des temps quaternaires.

II. TRANSGRESSIONS ET RÉGRESSIONS SUR LA PLATEAU CONTINENTAL

(*a*) *Transgression du Pliocène ancien.*—Le Pliocène ancien a été découvert à Régnéville (Manche) par Coatmen et Chavan et, comme il a été dit, par moi-même sur le Plateau continental marocain, entre Safi et le Cap Cantin. Il y forme des hauts-fonds hérissés, évoquant des strates plissées et érodées à −70 (grès littoraux de la transgression) et vers −500, sous forme de nodules cimentés par du phosphate de calcium, identiques à ceux de l'Agulhas Bank. Ces nodules, qui fossilisent des " boues à Globigérines," contiennent *Nassa semistriata.* Elles semblent isolées au cours d'une régression de la fin de la période. On sait, d'autre part, la pénétration profonde de la mer à cette époque, soit dans des *rias*, soit jusqu'à la " falaise des Phosphates," dans l'intérieur des terres.

(*b*) *Régression du Pliocène supérieur.*—Cette première observation donne déjà une mesure de l'importante oscillation du niveau des mers au cours de la période pliocène. Des galets très volumineux, presqu' exclusivement faits de quartz de filon ou de quartzites, cimentés par un ciment ferro-manganique, forment soit la partie supérieure des parois de la gorge du Rech Lacaze-Duthiers, cañon sous-marin au large de Banyuls-sur-mer (Pyrénées Orientales), soit le remplissage de cette vallée sous-marine, en partie recreusée au Quaternaire. Ces galets ne peuvent être comparés qu'au Villafranchien, rarement conservé dans les fentes de l'Astien du Roussillon, plus fréquemment sous forme des cailloutis résiduels des plateaux (Sicilien probable).

Le littoral villafranchien, dont il est possible que les fragments retrouvés à −70 au Maroc constituent un jalon, semble donc très au large du littoral actuel.

(*c*) *Dépôts siciliens.*—Des " marnes " bleues très compactes (qui sont d'anciennes vases) ont été arrachées des " vires " horizontales du Rech Lacaze-Duthiers. Je les ai retrouvées également sous forme de galets dans le remplissage du cañon de la Cassidagne (Cassis, Bouches du Rhône). Il semble que ce soient ces " marnes," renfermant *Terebratella septata*, que Marion a draguées dans les fonds que nous savons aujourd'hui faire partie du cañon sous-marin du Planier (Marseille). On peut rapporter ces marnes, qui ne renferment que des Foraminifères banaux à test minces, soit à du Plaisancien, soit, vu la position des dragages, beaucoup plus vraisemblablement à du Sicilien, c'est à dire en faire l'équivalent des " argiles bleues " de Ficarazzi en Sicile ou des Marais Pontins, portées exceptionellement haut dans ces deux localités par des mouvements orogéniques.

J'ai tendance à ranger le Sicilien, d'accord en celà avec le sentiment profond des anciens géologues italiens et les dernières tendances des paléontologistes américains, à la fin du Post-Pliocène. Bien que Haug et la plupart des géologues prennent les transgressions pour fixer les coupures de leur chronologie, ce rôle me parait être mieux joué par les régressions, qui correspondent toutes à des crises orogéniques et à de profondes transformations dans les climats continentaux.

(*d*) *Transgression du Quaternaire ancien atlantique.*—Le Quaternaire ancien à *Pecten amphicyrtus* et microfaune méditerranéenne a été découvert à La Baule les Pins, sous forme de grès cimentés par

de la calcite limpide, en épaves sur la plage. Des coquilles de ce Mollusque sont connues, vers le Nord jusqu'à Cherbourg, des galets du grès, vers le Sud jusqu'à la plage de l'Aiguillon (Vendée). Le facies est le même que celui des grès quaternaires du Portugal ou des " grès de Rabat " au Maroc. Si, d'après la faune chaude qui y est renfermée (*Pecten amphicyrtus* vit actuellement aux Canaries), on les classait, en suivant la classification de Lamothe et de Depéret, ils devraient caractériser la "plage de 30 mètres". Aucune trace émergée de ces grès n'est d'ailleurs visible (comme aucune formation marine certaine) à la cote +30 sur le littoral atlantique français.

En Méditerranée, j'ai recueilli les mêmes grès de plage, ou des dunes qui leur sont liées, toujours très fortement cimentés, aux points suivants: Barcarès de Leucate (Aude), Roches Notre Dame d'Agde (Hérault), Bandol (Var, découverte initiale de Mlle Pfender), Iles de Porquerolles et de Port-Cros, Iles d'Hyères, (Var, découverte initiale de Léger et Blanchet), à la Pointe du Tuf, près de Sanary (Var), à Monaco (découverte initiale de M. Thoral), à Saint Jean-Cap Ferrat (Alpes maritimes). Tous ces grès sont pétrographiquement identiques à ceux qui ont été cités plus haut de l'Atlantique. Ils sont toujours ravinés par des " alluvions anciennes " ou des " limons rouges," comprenant souvent, à la base, un niveau de grès dunaires, également très bien cimentés, qui représentent, vu leur microfaune, une oscillation transgressive.

Des échantillons qui renferment des algues calcaires ou des débris d'animaux caractéristiques du "trottoir" m'avaient été remis par Mlle Pfender. Ils proviennent de l'Ilet d'Antibes ou ont été dragués dans la rade de Toulon (—30). J'ai trouvé trace d'un pareil " trottoir " au Frioul (Marseille).

Quelle que soit la situation altimétrique des lambeaux de grès (elle varie de —30 à + 70), ils se présentent tous dans la même situation stratigraphique et sous le même facies pétrographique. Il en est du reste de même de tous les grès littoraux quaternaires auxquels on donne, en Méditerranée, des noms variés: *panchina* des Italiens, *poros* des Grecs, *ramleh* de Syrie, *marès* des Baléares, etc. Ce sont les homologues des grès tyrrhéniens ou monastiriens de Monastir (Tunisie), ou des " Grès de Rabat."

Des grès analogues ont été dragués à —21-30 sur le Plateau continental du Roussillon. Ils y forment deux longues dorsales nord-sud, parallèles au littoral actuel. Des calcaires gréseux très voisins ont été arrachés par les dragages, dans la même région, jusqu'aux abords du "talus" continental. Contenant des fragments de Corallinacées et des Foraminifères des Cystoséires, ils semblent presque littoraux.

Tous ces témoins de la mer du Quaternaire ancien indiquent que la côte était basse, sableuse, le continent sans grand relief. Dans les Iles d'Hyères, par conséquent, une profonde déformation orogénique a dû avoir lieu depuis leur dépôt.

Il semble que les couches à *Cardium umbonatum* que l'on trouve beaucoup plus à l'intérieur des terres (Capestang (Aude) par exemple) correspondent à une très large extension, à cette époque, des Étangs littoraux.

Les sables vaseux ou vases sableuses que Depéret et ses collaborateurs ont décrit au Cap Ferrat (près de Nice), avec une riche faune à *Strombus bubonius*, etc. (faune sénégalaise) semblent le reste de dépôts *côtiers* correspondant à ces dépôts littoraux.

Au Maroc, au Portugal et en Syrie, j'ai décrit de nombreuses coupes du littoral de cette époque, sur lesquelles on a abondamment discuté: de Cadix et de Tarifa (Espagne) au Rio de Oro, sans autre interruption notable que le Détroit de Gibraltar, on peut reconnaître:—

(1) Une première plage qui a été, à Rabat (localement, je crois), cimentée après émersion et érodée par le ressac et les embruns en " marmites."

(2) Une seconde plage qui remblaie ces marmites et qui passe, à la partie supérieure, à une dune cimentée où a été trouvé l'Homme de Rabat.

(3) Des marnes panachées de rouge ou des microgrès contenant un kjokkenmodding très riche en coquilles de *Purpura* et *Yetus*, d'*Archelix lactea*, d'ossements divers et de débris de silex (Formation de Témara). Après une intercalation de grès dunaires, contenant des Foraminifères marins (avec à Rabat une mince niveau de plage, à la base), vient une couverture d'alluvions anciennes ou de limons rouges (Acheuléo-moustérien).

Il semble qu'une coupure entre 1 et 2 ou entre 3 et 4 ne soit valable que localement et qu'il s'agisse en réalité de deux ensembles, l'un marin, l'autre continental, séparés par une profonde régression et une importante érosion.

La série de base des dunes n'est pas visible à la mer dans le Rharb, à Safi et à Mogador. La dune, la plus proche de la mer, isole souvent du continent des lagunes, communiquant plus ou moins largement avec l'océan (Sidi Moussa, Oualidiya, Puerto Cansado . . .). Elle peut n'apparaître que sous forme d'îles en mer: Skrirat, Fedhala, Mogador, ou même sous la mer (—30 à Mansouriah).

Les plages marines de base contiennent (G. Lecointre) des Mollusques sud-américains (*Trochatella trochiformis* et *Acanthina crassilabrum*).

On peut comparer la petite oscillation marine et dunaire, qui se trouve au sein des formations rouges, à celle qui existe à Porquerolles, à Monaco et au ramleh supérieur de Syrie, ainsi qu'au niveau de galets très bien roulés, probablement marins que l'on trouve un peu au dessus de la base des limons jaunes de Normandie et de Bretagne (Normannien = Moustérien *auct.*).

Suivant leur altitude, ces lambeaux d'alluvions anciennes ont été qualifiés de Sicilien ou de Milazzien. Au Maroc, l'intercalation marine et dunaire est attribuée au Tyrrhénien, au Monastirien en France. Rien pourtant dans leur faune ne permet de les assimiler aux couches marines: " argiles " profondes de Ficarazzi, à faune froide, pour lesquelles Doderlein avait créé le nom de Sicilien ou aux *panchina* à faune sénégalaise (Tyrrhénien d'Issel). Quant au Milazzien, à faune banale, son existence même a été révoquée en doute par Gignoux.

J'ai tendance à ranger tous ces lambeaux dans le Tyrrhénien, première transgression générale du Quaternaire. La question des " plages soulevées " sera discutée dans la troisième partie de cet exposé.

(*e*) *Alluvions anciennes, limons de la grande régression.*—Nous avons vu qu'en Méditerranée et au Maroc, les plages et dunes cimentées du Quaternaire ancien sont recouvertes par des cailloutis, limons ou sols rouges, datant de la grande régression. Celle-ci a été, pour la première fois, décrite par Marcellin Boule aux grottes de Grimaldi. Je lui ai, pour cette raison, donné le nom de Grimaldien. La faune, que renferme cette formation, au Maroc et en Algérie, est *soudanaise*, l'outillage qui y a été recueilli va de l'Acheuléen au Levalloisien (avec parfois du Moustérien typique). La dimension des galets, le façonnement en lapiez du bed-rock, montrent que les pentes étaient alors très fortes, les débits des rivières puissants. Des alluvions analogues, à patine rouge, ont été draguées en Méditerranée, notamment contre la dorsale dunaire submergée du Roussillon, sur le plateau de Planier (Marseille) et au large des îles d'Hyères.

Cette formation correspond sur les côtes de la Manche (Normandie, Bretagne) et de l'Atlantique (Bretagne, Vendée, Charentes) à des limons jaunes, souvent aréniques (présentant à la base une intercalation de galets marins) qu'on a souvent, à tort, confondu avec le *head.*

J'ai montré que ces limons, ou leurs blocaux de base, se prolongent loin sous la mer et que, notamment, ils constituent souvent le substratum des plages.

Sur la côte des Landes, ils correspondent à des " alluvions anciennes " altérées qui, dans les collines sous-pyrénéennes, forment des coulières (Lande de Pontacq, par exemple) qui passent en tunnel sous les sables des Landes et sont rassemblées en cordon sur le bord du Plateau continental.

Cette dernière disposition a déjà été figurée par Delesse en 1871. Mais l'étude pétrographique des éléments du cordon rejetés sur les plages par les tempêtes permet de les identifier et de les attribuer à une coulière déterminée.

Le facies jaune se continue jusqu'à la frontière hispano-portugaise. Il fait place, dès le Minho, au facies rouge. L'un et l'autre correspondent à une profonde altération des granites, moins accentuée peut-être que celle du Villafranchien.

Je considère que les graviers et sables côtiers de l'Atlantique et de la Méditerranée, les cailloutis de toute la Manche (à l'exception des cailloux anguleux du *head* sous-marin) proviennent du triage de ceux de la base des limons. Les " sables et graviers du large " (–70-150), ceux qui remplissent, sous

la vase à *Cyprina islandica*, les cañons sous-marins, datent de cette grande régression, dont la limite reste à fixer.

(*f*) *Formations datant de l'époque froide* (*glaciaire?*).—Sur les côtes de la Manche et de l'Atlantique, le *head* (coulées boueuses périglaciaires), des loess subordonnés, puis des argiles de marais et des tourbes à *Pinus*, succèdent aux limons et alluvions anciennes. Plusieurs alternances de transgression et de régression se sont alors produites: invasion d'une mer déposant des vases et des tangues, régression correspondant aux dunes néolithiques (avec un kjokkenmodding à la base), transgression récente (décrite par Guilcher dans la Baie d'Audierne). Les dunes de cet âge sont, au Maroc, encroûtées et non cimentées.

L'oscillation régressive correspond sur le plateau du Golfe du Lion à un dévasement qui a isolé la faune froide à *Cyprina islandica* que l'on trouve comme résidu dans les " sables du large." Celle-ci avait été considérée autrefois par Pruvôt comme sicilienne. Elle est incluse dans les 50 centimètres de vase dont le dépôt se continue aujourd'hui et qui recouvre les cailloutis des cañons roussillonnais.

Si l'on exclut le Sicilien, sur la signification duquel on n'est pas d'accord, il n'existerait donc au Quaternaire que deux transgressions, la première, en général d'eau chaude, celle du Tyrrhénien *sensu largo*, la seconde, d'eau froide, celle du Flandrien, séparées l'une de l'autre par un épisode de grande régression et de tuméfaction continentale qui reproduit, en plus petit, celui du Villafranchien. Les autres oscillations peuvent êtres comprises comme des harmoniques des premières.

Il est impossible d'interpréter ni cette alternance de transgressions et de régressions, ni la situation actuelle des lambeaux subaériens ou sous-marins conservés, le rythme des dépôts successivement fins ou grossiers, par la seule hypothèse eustatique, surtout sous la forme que lui a donné Tylor (rétension glaciaire). L'hypothèse d'un gonflement rythmique des continents et d'un plissement du fond des mers en mégasynclinal de part et d'autre d'un axe, variable dans sa position, que j'ai appelé *flexure continentale*, permet d'expliquer tous ces faits par les seules contractions et détentes de l'écorce. Elle ne se limite pas, d'ailleurs, au seul rythme du Quaternaire, mais elle est applicable à l'ensemble des transgressions et des régressions de l'histoire géologique.

La croyance presque universelle à l'eustatisme glaciaire et aux côtes fixées, sur des bases très contestables, par le Général de Lamothe et Charles Depéret ont fait que cette hypothèse, en principe, n'a pas été prise en considération, sauf par Du Toit, Jessen et Umbgrove. Il m'a surtout été reproché de ne pas l'avoir démontrée. Je tenterai de le faire dans une troisième partie. J'essayerai maintenant de montrer que ce que nous avons appris de la morphologie du Plateau continental, ne peut être, pour l'instant, expliqué que grâce à cette hypothèse.

III. MORPHOLOGIE DU PLATEAU CONTINENTAL

Les recherches, effectuées depuis la guerre, ont montré que la surface du Plateau continental n'était pas lisse. Dans le Golfe du Lion nous avons mis en évidence divers exemples de reliefs rocheux; des dunes ou des cordons parallèles au littoral actuel, les plateaux hérissés de la région de Banyuls: Ouillals-Canalots-Ruine, qui paraissent faites de strates inclinées. A Marseille, le Plateau a une topographie continentale, soupçonnée dès le XVIII[e] siècle par le Marquis de Marsilli, figurée en 1883 par Marion. Une véritable falaise, les Mangespen, réunit, par exemple, le Cap Croisette à l'îlot de Planier. Elle représente le bord d'une terre émergée qui comprenait toutes les îles de Marseille.

Le relief des îles d'Hyères se projette loin sur le Plateau continental jusqu'à des fonds de -80 m.

Le Plateau continental marocain, outre les mêmes cordons ou dunes sous-marins, vers -30, offre dans la région entre le Cap Cantin et Safi, les rochers pliocènes dont nous avons parlé. Ce sont des crêtes aiguës, émergeant à -40 de fonds de -70. Un relief sous-marin très complexe existe en prolongement du Cap Rhir.

Bien qu'il soit actuellement impossible de dire si le Rebord continental est partout dans l'Atlantique une falaise (ou une *cuesta*), c'est souvent le cas dans le Golfe de Gascogne où un à-pic rugueux a été mis en évidence par le " Caudan." Il en est de même à l'entrée de la Manche, d'où les chalutiers de La Rochelle ramènent des Coralliaires branchus.

Dans le Golfe du Lion, une falaise borde toujours les nombreux cañons sous-marins qui entaillent le Plateau. Les pédoncules qui les séparent, en revanche, ont des formes plus douces, mais toujours convexes: ils sont comparables aux rameaux de lignes de crêtes d'une chaîne de montagnes. Aucune véritable falaise n'a pu, jusqu'ici, être mise en évidence au Maroc, où la descente est pourtant très rapide; elle paraît aussi convexe.

La théorie de Murray doit donc, probablement, être abandonnée: le Plateau n'est pas le lit de déjection des produits de l'abrasion marine.

La théorie de Richthofen n'est pas plus adéquate aux faits connus; ce ne peut être l'abrasion marine qui est responsable de l'applanissement du Plateau. En effet, l'étude de détail montre que le Plateau a un modelé en creu, entièrement préservé: cours sous-marins de rivières, dans sa partie la plus proche de terre, cañons entre −90 m. et le pied du Rebord continental.

D'autre part, des sédiments meubles continentaux à peine remaniés et transformés, le couvrent; les *graviers côtiers*, provenant du triage de dépôts fluviatiles ou de sols grimaldiens et les *sables et graviers du large*, probablement de même origine, mais moins vannés. Passant l'un à l'autre dans les zones battues, ils sont séparés le plus souvent, entre 30 et 90 mètres par les vases de la Grande Vasière.

Les *cañons sous-marins* du Golfe du Lion ont fait l'objet de recherches que l'on peut comparer aux résultats obtenus aux États-Unis, notamment par Shepard et Stetson. Le Gouf de Cap Breton, dans le Golfe de Gascogne, est peut-être le plus anciennement connu de ceux-ci, discuté dès la *Face de la Terre*. Peu de temps avant la guerre, il avait été levé par le Ct Beaugé du *Président Théodore Tissier* et J. Furnestin avait arraché de l'Eocène de ses parois. La carte du Golfe du Lion avait été levée en 1936-1937 par Marti, l'inventeur du sondage par échos: 14 cañons y sont figurés entre Banyuls et Toulon. Il faut y ajouter, au Sud, dans les eaux espagnoles, le Rech du Cap, découvert par Pruvôt, le cañon de la Ciotat et, d'après V. Romanowsky, deux cañons dans la Baie des Anges (Nice). Nous avons levé au sondeur continu deux de ces cañons: le Rech Lacaze-Duthiers (Banyuls-sur-mer) et le Cañon de la Cassidagne (Cassis, Bouches du Rhône).

L'un et l'autre commencent vers −90 m. et se terminent vers −2.000 m.; l'un et l'autre sont rocheux et ont une morphologie de gorges de montagne. Ils sont remplis par de la vase à coquilles boréales (*Cyprina islandica*, *Chlamys islandica*, *Astarte sulcata*) recouvrant un gravier à éléments bien roulés pouvant atteindre 2 cm. de grand axe. Dans le Rech Lacaze-Duthiers, ce cailloutis provient en partie des Corbières ou d'une couverture pyrénéenne disparue des Albères; dans le cas du cañon de la Cassidagne, ce sont des éléments duranciens. Il faut aussi mentionner des galets des " marnes " siciliennes.

La découverte d'un conglomérat à très gros éléments, vraisemblablement villafranchiens, dans le Rech Lacaze-Duthiers, permet de lui assigner —et par extension aux autres—un âge pliocène supérieur (et non le dernier Glaciaire). Un recreusement partiel a pu se faire pendant la grande régression grimaldienne.

A cause de ces résultats, je pense de plus en plus à une explication fluviale pour ces cañons. Les théories de Wegener (failles), de Bucher (tsounamis), de Johnson (érosion souterraine), n'ont aucun caractère de généralité. Quant à celle de Daly, que les expériences de Bell et de Kuenen tentent de démontrer, la nature rocheuse des parois de ces deux cañons, leurs méandres et affluents; les graviers du remplissage, la rendent hautement improbable, au moins comme cause première.

La seule objection que l'on avait faite à la théorie du creusement fluvial lors d'une régression, me semble disparaître si l'on admet que le Plateau s'est abaissé à partir d'un axe de flexure, situé non loin du littoral actuel.

Il est, par ailleurs, beaucoup plus vraisemblable d'admettre un mouvement aussi important au Villafranchien, époque de la surrection du relief pyrénéen qu'au Grimaldien. J'ajouterai que l'existence de véritables cañons au large de Nice, Villefranche, Menton, indique que l'absence de Plateau continental n'y est qu'apparente, mais qu'en réalité celui-ci est déformé et très incliné, ce qui serait le cas chaque fois qu'une chaîne lui est parallèle ou s'y termine brusquement par inflexion axiale.

IV. DÉFENSE DE L'HYPOTHÈSE DE LA FLEXURE CONTINENTALE

La stratigraphie du Quaternaire est souvent basée sur l'étagement de " plages soulevées."*

La doctrine classique qui en est issue, inspirée par les idées d'Eduard Suess sur l'origine des transgressions et des régressions marines, a été formulée dans toute sa rigueur par le Général de Lamothe (travaux sur le Sahel d'Alger) et par Ch. Depéret (Nice). Les faits stratigraphiques sur lesquels se sont appuyés ces auteurs ont été contestés et sont contestables (existence propre du Milazzien à Milazzo (Gignoux), du Monastirien à Monastir (Solignac, Denizot et, récemment, Laffitte), âge des gisements de Nice). Mais je voudrais montrer que, du point de vue océanographique, où la théorie n'a jamais encore été examinée, de graves critiques de principe doivent être formulées.

Si je ne trahis pas la pensée des premiers auteurs, et en limitant l'examen à la Méditerranée, mer en cuvette, où la théorie a pris naissance, l'idée qu'ils se faisaient de l'évolution de la mer au cours du Quaternaire, était une série d'abaissements du niveau par *saccades* (sans prendre ce mot au sens littéral, sa signification étant plutôt de rapides abaissements du niveau et, par conséquent, de rapides reprises du creusement fluvial), séparées par des phases assez longues de stationnement. Cette hypothèse n'a aucun besoin de s'appuyer sur l'existence de périodes glaciaires avec rétension des eaux de précipitation et baisse consécutive des niveaux fluviaux et marins. Elle est aussi bien applicable au Pliocène ou même au Miocène. Mais les plages étagées doivent appartenir à un même niveau océanographique.

Une première complication résultait de l'existence de variations dans la composition lithologique et faunistique (le facies) des différents dépôts déja reconnues par les géologues italiens et précisées par Gignoux.

Les dépôts authentiquement *siciliens*, qu'ils soient quaternaires ou pliocènes (Ficarazzi, Marais pontins) sont des " vases du large " contenant notamment des Brachiopodes (prof. —200 m.). Ils ne peuvent appartenir qu'à la zone qui est au large du Plateau continental ou à des dépôts de cañons. Les argiles siciliennes renferment une faune froide de l'Atlantique nord; mais l'apparition de celle-ci en Méditerranée n'implique qu'une profondeur suffisante pour que les adultes puissent survivre ou, pour les larves planktoniques, une plus large pénétration en surface des eaux atlantiques dont le résultat est un refroidissement beaucoup plus rapide que celui qui serait dû à une variation de climat.

Les dépôts à faune banale (Milazzien?) et à faune chaude avec *Strombus bubonius* et *Conus mediterraneus* (Tyrrhénien et Monastirien), c'est à dire tyrrhéniens dans le sens d'Issel, sont de caractère assez différent: ce sont soit des plages à sable quartzeux (Monaco, Sanary, Bandol, Iles d'Hyères, Agde, Leucate) toujours liées à des dunes cimentées (cote 0), soit de " trottoirs " (Ile Ratonneau, cote −2), soit des dépôts du " broundo " sables " coralligènes " à Bryozoaires, Lithothamniées et Polypiers (—25-30 m.) qui renferment les coquilles de grands Strombes, soit des " sables vaseux " (−40 m.) avec la même faune (Vaugrenier et probablement Cap Ferrat). Les uns et les autres appartiennent donc aux zones littorale et côtière. Ils sont, à la base, riches en cailloutis qui représentent des sols continentaux résiduels. D'une façon générale, la côte était alors sableuse, basse et plate.

Les dépôts récents du Flandrien (Basse Versilia (A. C. Blanc), Salanque de Perpignan, Aleria en Corse) sont des vases d'Étangs ou de limans, ou des sables fins de deltas, déposés à une cote égale ou légèrement supérieure au niveau de la mer du moment. Ils correspondent à un débit abondant et régulier de rivières calmes et recouvrent les alluvions rougeâtres, grossières, du Grimaldien qui, elles, impliquent un régime torrentiel des cours d'eau.

Ajoutons que les dépôts siciliens caractérisés sont rares, ceux du Tyrrhénien abondants, mais sporadiques, et qu'ils existent même sur les côtes actuellement rocheuses et au niveau des pointes, toujours conservés sous forme de témoins exigus. Seuls ceux du Flandrien sont intacts, mais ils occupent uniquement des régions basses: vallées ennoyées, étangs littoraux.

*A. Bigot a critiqué cette dénomination; dans la pure hypothèse eustatique, il vaudrait mieux dire plages-témoins. Il est également abusif de parler de plages pour des témoins de plateformes d'abrasion ou même pour des laisses de galets.

Une seconde complication a été introduite, à la suite des études de Boule sur les grottes de Grimaldi, par l'extension au Quaternaire des idées des géologues sur l'existence de très grandes régressions.

Marion, dans son beau travail de 1883, sur le Golfe de Marseille, toujours cité, jamais lu, avait déjà mis l'accent sur la nécessité d'expliquer l'existence, dans les brèches ossifères du Frioul dans les îles marseillaises, d'*Ursus mediterraneus* et d'*Histrix major*, par la réunion de ces îles à la terre ferme. Il avait montré que, topographiquement, Planier, Ratonneau, Pomègue se soudaient au Cap Croisette par la falaise sous-marine des Mangespen. On peut aujourd'hui dire que toute cette région submergée de l'Est de la rade de Marseille, n'était qu'un grand " karst " avec sa topographie tourmentée, ses cailloutis, antérieurs à l'assèchement par érosion souterraine, et sa " terra rossa."

Les preuves de l'existence d'une vaste régression, postérieure aux couches à Strombes (Tyrrhénien *sensu largo*) sont extrêmement nombreuses, non seulement sur les côtes de la Méditerranée ou du Maroc (ce sont les " marnes roses " de Témara et les limons rouges, coupés par une courte oscillation marine), mais même sur celles du Golfe de Gascogne et de la Manche.

Cette régression n'est pas la seule: A. C. Blanc, dans son étude stratigraphique des Marais pontins, en a admis une première, entre le Sicilien et le Tyrrhénien (tufs de la Roche Tarpéïenne). Les coupes que Denizot a données pour étayer sa critique du Monastirien impliquent une autre régression, au moins sur l'extrême bord du littoral. Il en est de même pour la coupe que nous avons relevée, G. Choubert, J. Marçais et moi-même à Rabat; une première plage cimentée y a été érodée par le ressac et les embruns avant le dépôt d'une seconde, liée à la dune, qui moule ces marmites (v.p. 7). Cette disposition, que je crois aussi, uniquement localisée au bord du littoral, implique pourtant, par suite de la cimentation intervenue avant la seconde plage, une émersion au moins limitée de la première, avant le dépôt de la seconde.

Des considérations sur l'isolement de la faune endémique particulière à chaque île ou îlot de Marseille, comme de celle des îles dalmates, évoquent aussi des régressions très récentes. L'étude des dépôts meubles sous-marins (head, argile bleue, tourbes diverses) de la Manche m'a conduit à des conclusions analogues, comme d'ailleurs celle des fonds du Plateau continental du Golfe du Lion. On sait que les géologues et pédologues hollandais ont décrit une série de régressions et de transgressions préhistoriques, protohistoriques et historiques.

L'idée d'une alternance rythmique entre transgressions et régressions suggérait l'image d'un sismogamme avec des oscillations amorties du niveau marin (Joleaud).

Mais, dans ce cas, les plages (et les dunes) ne peuvent être que celles abandonnées par la régression. Toute transgression pousse, en effet, vers l'intérieur du continent le prisme des dépôts littoraux sableux. Pour peu que la pente soit suffisamment faible, la mer en s'en allant, en revanche, abandonne des sables, plus ou moins remaniés ensuite en dunes. Le fait est bien connu dans tous les bas pays, notamment en Hollande, à Carterêt, dans les Landes. Il est, par contre, à peu près impossible que des témoins de plages ou de dunes puissent se conserver au droit de pointes ou si la régression laisset un littoral à forte pente. Dans ce cas, la mer entraîne vers le large la totalité des sables de la basse plage et ne peut laisser que des blocs ou, à la rigueur, des galets. Le maintien, sur des côtes escarpées, de témoins de plages ou de dunes, comme aux îles d'Hyères, implique: (1) que le profil de la côte et du Plateau s'est profondément modifié depuis leur dépôt, dans le sens d'une accentuation des pentes; (2) que les plages et dunes, actuellement falaises ou platiers, avaient été cimentées au cours d'une régression. La cimentation par de la calcite en grands cristaux, d'après tout ce que l'on sait des formations actuelles, ne peut se faire qu'après émersion. (3) La succession des niveaux quaternaires, au bord de la mer sur les falaises de Rabat ou à la Carrière Sidi Abderrahmane à Casablanca, ne correspond ni à une série de plages étagées, schéma toujours figuré dans les Traités, ni à des plages emboîtées, comme celà devrait se produire si des intervalles de régression et d'attaque par la mer séparaient des intervalles de dépôt, mais elle correspond à une superposition de niveaux successifs:

(*a*) Plage avec petits cordons de graviers, cimentée et creusée de marmites par les embruns.

(*b*) Plage avec laisses de coquilles passant à la dune cimentée.

(*c*) Dépôt d'argiles de marécage (boues) rougies par des apports de ruisseaux remaniant des limons rouges.

(*d*) Dépôt d'une plage très mince, ou d'une dernière dune cimentée.

(*e*) Dépôt des limons rouges ou d'alluvions caillouteuses.

A Casablanca, MM. Neuville et Ruhlmann ont interprété cette disposition en supposant que les niveaux 1 et 2 représentaient des sédiments profonds. Certains arguments pour justifier cette interprétation sont fondés sur les espèces des coquilles des laisses de tempête, notamment sur l'existence du *Pectunculus glycimeris*, fortuitement cité à —90 m. dans le catalogue de Pallary.

Il est pourtant connu que la composition d'une laisse de tempête varie avec la force de la houle. Par tempête d'équinoxe, celle de Quiberon-Penthièvre est surtout faite d'*Echinocyamus pusillus*, Échinide du maerl (au moins —15 m.).

Une pareille conception, du point de vue océanographique, est inacceptable: au large du littoral marocain, les dépôts s'étagent sur le Plateau de la façon suivante: de 0 à 15 m.: sables littoraux, souvent grossiers, de 15 à 40 : sablons ou sables très fins limons rouges sous-marins remaniés par la houle profonde (sur les côtes méditerranéennes, cailloux résiduels du " broundo "), de 40 à 100: vase côtière, de 100 au Rebord continental: sables, graviers et galets du large.

Les formations conservées après cimentation, dans les deux cas de Rabat et de Casablanca, sont toutes deux des sables entremêlés de graviers et de laisses de coquilles. Ils ont été déposés au voisinage de la cote 0 sous forme le plus souvent de cordons. On sait que ce type d'accumulation implique une côte très peu profonde et plate. Si l'on fait passer actuellement un plan par la base de ces cordons ou dunes, on obtient une pente de 3 à 4%, ce qui est beaucoup trop fort.

Enfin, les cailloutis de la base des limons rouges ont été dragués jusqu'à la profondeur de — 40 (Mansouriah), des fragments cimentés de limons contenant des coquilles d'Escargots sont rejetés très au large à Témara et à Mazagan.

Les défenseurs de la théorie eustatique ont, enfin, relevé dans l'estuaire du Bou Regreg, des terrasses étagées aux altitudes classiques de 90, 60–70, 30, 6–8. Si ces terrasses étagées existent réellement, en revanche, entre Rabat et Salé, dans l'estuaire, les formations 1, 2, 3 et 4, les deux premières deltaïques, les deux dernières vraiment fluviales, sont *superposées*; les niveaux 1 et 2 disparaissent rapidement sous la mer et la dune ancienne est entaillée par elle en falaise aux Oudaïas. Il est donc impossible de restituer la coupe sans admettre, comme l'a fait Oestreich en Hollande, un *entrecroisement* successif des terrasses: le niveau 1 croisant le niveau 2, le 2, le 3, etc. Comment peut-on interpréter alors cet entrecroisement? Quand des formations fluviales ou marines sont étagées, les plus hautes étant les plus anciennes, cela veut dire que le fleuve est descendu toujours plus bas soit, dans l'hypothèse eustatique, parce que le niveau marin a baissé, soit, pour ses adversaires, parce que le continent s'est élevé.

Au contraire, la disposition qui existe vers la mer: superposition des niveaux les plus récents sur les plus anciens, classique dans tous les bassins de sédimentation, ne peut, sans changement de facies, s'interpréter dans l'hypothèse eustatique, que par une montée du niveau marin ou, autrement, par un abaissement du continent. Il est donc superflu d'insister sur le fait que l'hypothèse eustatique conduit à une contradiction insoluble. Dans le cas contraire, l'entrecroisement peut s'interpréter facilement en admettant une surrection de l'intérieur du continent et un affaissement vers la mer, c'est à dire par une déformation anticlinale à l'intérieur, synclinale vers le large. La limite de ces deux mouvements inverses est la " flexure continentale." Cet axe de changement de sens dans la déformation ne coïncide pas nécessairement avec le littoral: il peut être situé en mer (côtes en surrection, très attaquées en général) ou à l'intérieur des terres (bas pays littoraux).

L'importance de la déformation, de part et d'autre de l'axe, est variable tout le long d'un littoral, de même qu'un anticlinal s'ennoie axialement et passe à un synclinal. La position de la flexure, elle-même, varie au cours des temps géologiques. Mais j'ai surtout insisté sur le fait que les déformations des continents et du fond des océans que j'imagine ne sont pas définitives pas plus que celles des chaînes de montagnes (méga-anticlinaux). Le plissement peut s'effacer à certaines époques, se

" détendre." L'étude lithologique, granulométrique notamment, des dépôts sur le Plateau à l'époque, permet de fixer ces intervalles de *tuméfaction* et de *détente*: galets, graviers, sables, caractérisent les *périodes de contraction* où les pentes sont fortes; les sédiments fins: vases (qui deviennent marnes ou argiles), calcaire (absence de sédiments terrigènes), les moments de *détente*. Umbgrove, après bien d'autres, a souligné ce rythme et l'a lié au volcanisme et aussi aux variations locales de climat.

Enfin, on m'a reproché de n'avoir imaginé la " flexure continentale " que pour expliquer les faits que je croyais avoir observés au Maroc. C'est toute une autre série d'observations qui sont à l'origine de cette idée: le contraste entre l'ennoyage des fjords, rias et calanques et les formes extrêmement jeunes de toute leur partie amont, indiquant un pays en voie d'attaque très vive par l'érosion, donc en *surrection*. En amont de l'estuaire ennoyé du Bou Regreg (Rabat), la couverture très plate de Quaternaire et de Pliocène disparaît, érodée, pour faire place à ce que G. Lecointre appelait un pays de " montagnes en creux," le " Korifla." Ce dégagement n'est possible qu'en admettant une surrection à l'intérieur, contemporaine de l'ennoyage.

J'ai aussi voulu marquer que les déformations continentales positives qui expliqueraient ce rajeunissement et l'encaissement des cours d'eau ne peuvent être dues à une " surrection en bloc " des continents. Celle-ci ne serait possible que si ces continents étaient limités vers l'Océan, comme le voulait Wegener, par une faille.

Tout au contraire, ce que nous savons aujourd'hui de la géologie du Plateau, laisse au supposer qu'il est une partie du Synclinal Océanique.

PROBLÈMES DE TECTONIQUE PROFONDE EN MÉDITERRANÉE OCCIDENTALE

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RÉSUMÉ

La compilation des données gravimétriques en Méditerranée occidentale et dans les pays avoisinants (France, Suisse, Italie, Espagne, Afrique du Nord) a permis d'établir une carte des anomalies de Bouguer qui montrent l'existence d'une série de zones anomaliques positives et négatives.

L'interprétation tectonique de ces anomalies a été conduite suivant une hypothèse générale, différente de l'hypothèse classique de Pratt ou d'Airy, développée par l'auteur dans des publications antérieures. Le bassin méditerranéen apparaît alors comme sensiblement en équilibre isostatique.

Le problème des liaisons entre les différents fragments de la chaîne alpine fait l'objêt d'une discussion spéciale dont la conclusion est l'existence d'une série d'ondulations profondes signalées içi pour la première fois. Un schéma tectonique des plis alpins dans la Méditerranée occidentale et des régions avoisinantes est joint.

OLD BEACHES IN THE MEDITERRANEAN

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ABSTRACT

Bathy-lithological maps of the submarine part of various deltas in the Mediterranean and Adriatic show that sand only is deposited down to the −10 m. contour line. The boundary between sandy mud and mud occurs in this area at about −30 m.

The occurrence of sands in older formations, therefore, indicates deposition near the coast or on the continents.

THE general assumption that gravel and sand occur near the coast in shallow water and sandy mud and mud in deeper water does not hold in all cases. The distribution of these sediments is sometimes rather irregular.

From a study of bathy-lithological maps of recent deltas, however, it seems that the original assumption is true. Mud occurs already at a depth of 3 to 20 m. in front of the mouths of the Mississippi, Orinoco, Niger, Yang-tse-Kiang, Rhône, Po, Tiber, Nile, Ebro, and Danube rivers. The sand at the coast does not pass the −20 m. contour line. In deeper water, however, sand again occurs. These sandy areas are surrounded by sandy mud and mud. The sand cannot have been transported from the river mouths in present times.

Various areas of the continental shelf also consist of gravel and sand to a depth of 200 m. Bourcart (1938), Shepard (1932), Stetson (1938) and many others point out that the coarse sediments of the shelf have been deposited during the Pleistocene and even older periods and have not been covered with younger sediments.

Heavy mineral studies of bottom samples of the North Sea and Java Sea confirm this theory. The mineral associations of these deposits are not being supplied by the present rivers (Baak, 1936, and van Baren). In the southern North Sea the Pleistocene fluviatile deposits hardly have been transported by the sea. In the Java Sea the older sand deposits have been covered with younger sand and mud only in a strip along the coast. These younger deposits have a different mineralogical composition.

Many bathy-lithological maps have been published of the Mediterranean coasts. The papers in which these maps have been published are not generally known to geologists and therefore will be referred to here.

Thoulet (1912) studied the deposits of the Golfe du Lion in 1912 and Chevallier (1917) continued this study further east. In 1936 d'Arrigo published maps of the Rhône, Po, Nile, and Tiber deltas and of parts of the Adriatic and the North African coast.

The maps of Thoulet and Chevallier show that except for a few localities the coastal sand does not pass the −15 m. contour line. Currents are not very strong along the coast, maximum 80 cm./sec. at the surface. The influence of the tide is negligible but the surf may be rather strong.

In front of the mouth of the Rhône river (Fig. 1) sand occurs to a depth of 20 m. only at one spot, generally it occurs within the −10 m. contour. Below −30 m. mud occurs all around the present delta.

The Var river, which reaches the Mediterranean near Nice, carries pebbles and gravel down to the beach. At a depth of 20 m., however, sandy mud and mud occur. The submarine front of this delta is steep and creep of the deposits may occur.

At the mouth of the Nile River at Rosette and Damiëtte mud is being deposited at present. Sand occurs at the beach and dunes, in the Gulf of Aboukir and in front of Fort 5. The main submarine part along the delta consists of mud and sandy mud (Fig. 2). The current along the coast has a velocity

of 74 cm./sec. and is directed toward the east. The predominating wind direction is north-north-west, and the wave activity is strong.

The coastal sands in front of the Po delta (Fig. 3) are limited between the —20 m. line. At this contour mud deposits occur in a 2,500 m. broad strip all around the delta. Current, wind, and wave action are not very strong.

The above data show that sand transported by the rivers is deposited in the sea between the coast and the —15 m. contour line.

In deeper water in front of these deltas, however, again sands occur. South of the lighthouse Faraman, west of the present Rhône mouth, sand occurs at a depth of 35 m. In front of the Nile delta sand is found in narrow strips even at the —100 m. contour. These patches are surrounded by sandy mud and mud. Some of these sandy areas form ridges. The outer one occurs 45 km. off the coast. The deeper part of the Adriatic also has sand and muddy sand as bottom deposits, and a submarine ridge occurs at —25 m. throughout the entire northern part.

These phenomena show clearly that the deeper sands cannot have been supplied by the present rivers. They must be old, sandy surfaces. The sand has been deposited at lower stages of the sea level during the Pleistocene and probably older periods.

The distribution of the sandy patches in front of the Nile delta has a shape which is very similar to that of the coast lines of present deltas. When the old submarine sands occur not too deep current and wave-action keeps the material at their surface moving, and either mud is not deposited or it is washed out again after deposition. In the surrounding mud area deposition of mud may continue or be more or less interrupted.

The ridges occurring at a depth of 25 to 30 m. in various parts of the Mediterranean will be old dune areas.

The evidence given is of great importance for future oceanographic surveys and for studies of recent sediments and environments. Many so-called marine sands will have been originally laid down as fluviatile deposits and been reworked by marine action after transgression of the sea. In the latter stage marine organisms have been introduced wiping out the fluviatile origin.

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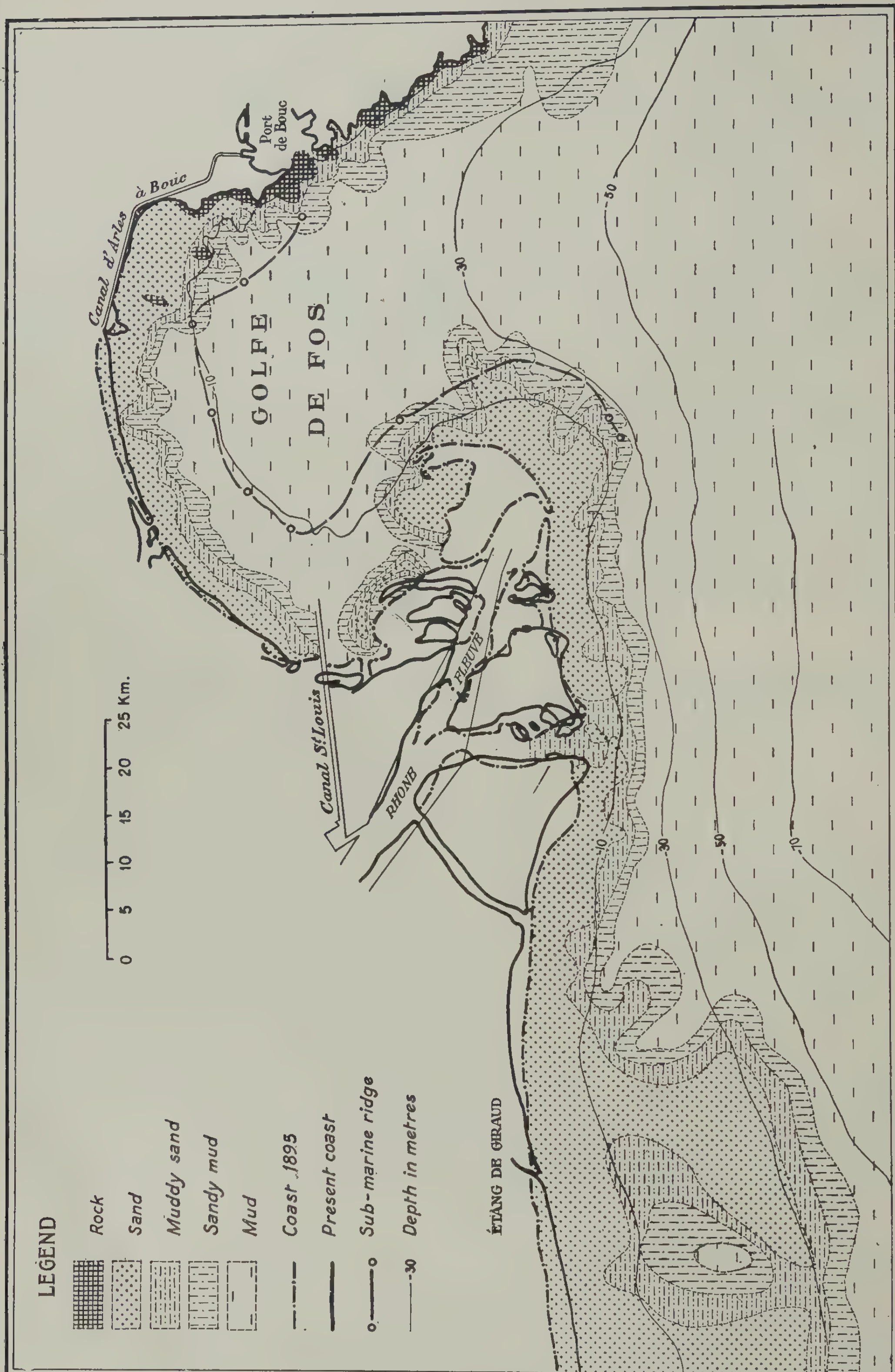

FIG. 1.—*Bathy-lithological map of the Rhône Delta in 1895 (after d'Arrigo).*

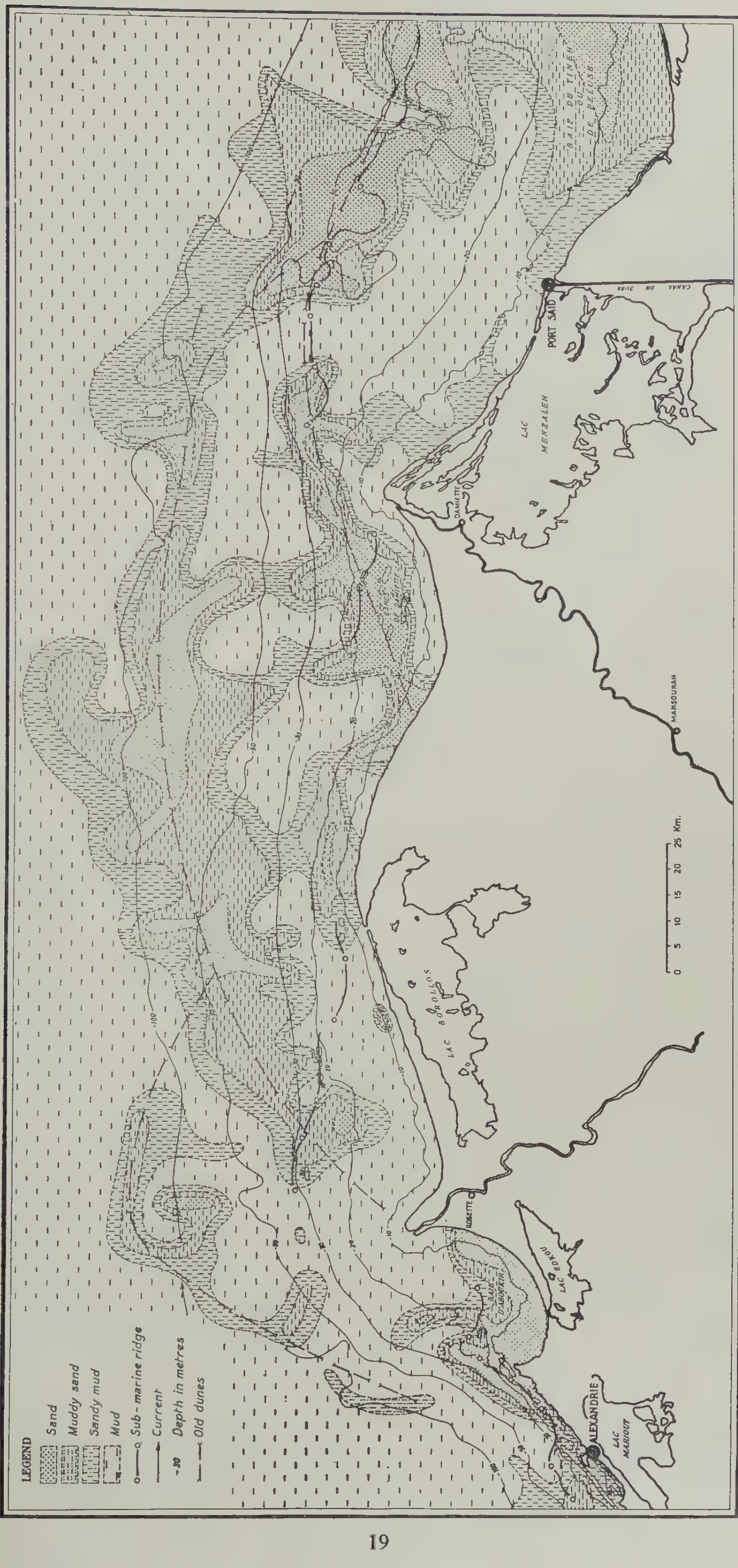

FIG. 2.—*Bathy-lithological map of the Nile Delta in 1920 (after d'Arrigo).*

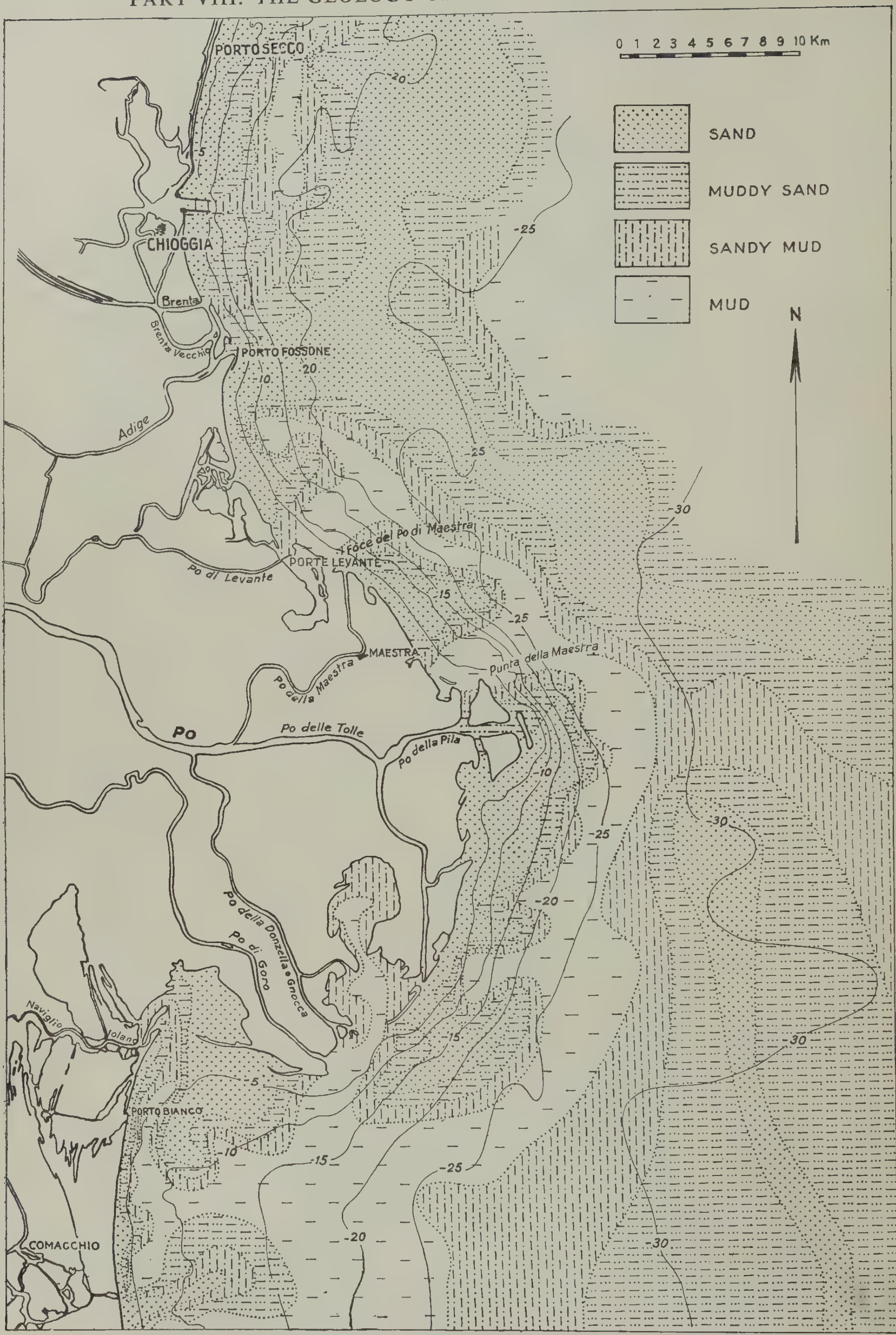

FIG. 3.—*Bathy-lithological map of the Po Delta in 1885 (after d'Arrigo).*

THE FORMATION OF BEACHES

By D. J. DOEGLAS

Netherlands

ABSTRACT

The results of daily micro-topographical measurements of the changes of a beach and of mechanical and mineralogical analyses of the Dutch beach sands support the conclusion of Timmermans that beaches are formed mainly by the action of waves alone.

Five groups of size frequency distributions occur along the beach between Hook of Holland and den Helder. The limits of these groups are sharp. Two mineralogical groups occur also.

The sharp limitation of these groups proves that transport normal to the coast dominates strongly the long-shore movement.

SUBMARINE GEOLOGY AND HYDROGRAPHY IN THE NORTHERN MARSHALLS *

By K. O. EMERY, J. I. TRACEY, Jr., H. S. LADD.

U.S.A.

ABSTRACT

The atomic bomb tests at Bikini in 1946 provided an opportunity to study the characteristics of atolls using modern surveying techniques. The work has shown that many of the important features, both above and below sea level, are definitely related to the direction of the prevailing winds, waves, and currents.

Beyond the windward (north and east) reefs of Bikini, the steep outer slope is broken in most places by a terrace at 10 fathoms. The margin of the windward reef is a *Lithothamnion* ridge, cut by strong grooves or surge channels; large islands are developed on these reefs. Lee reefs have nearly vertical outer slopes near the surface; their margins are smooth and are adapted to light surf; occasional storms have eroded large " slump areas"; the islands are small and few in number. Passes are largely confined to the southern reefs.

The lagoons of the atolls studied measure 25 to 35 fathoms and are bordered by a 10-fathom terrace. The floors are covered with living *Halimeda* and algal debris surrounded by a belt of foraminiferal and coral sand. Steep coral knolls, some rising nearly to sea level, are scattered in the lagoons.

Many submerged, flat-topped seamounts are present in the area. The 14 that were well surveyed rise from 2,500 fathoms to depths between 470 and 850 fathoms.

INTRODUCTION

IN connection with the atomic bomb tests at Bikini Atoll studies were made of the outer slopes of the atoll, of the reef and islands, and of the enclosed lagoon. For comparison, the nearby atolls, Eniwetok, Rongelap, Rongerik, and Ailinginae also were investigated. All of the atolls are at the northern end of the Marshall Group, a region in which the wind, the swell, and the ocean current generally move in a westerly to south-westerly direction. Even the most casual examination of the charts of the Marshall Group indicates a prevalent orientation of various features of the atolls in relation to exposure, or to direction of the prevailing winds. Other similar relationships were observed by studies of aerial photographs and by field work in the area.

OUTER SLOPES

Soundings taken during the survey show that the atolls rise from depths of about 2,500 fathoms on slopes which are steepest near the surface of the ocean. The top of the outer slope bordering the reef on the leeward side of Bikini and the other atolls is nearly vertical, but the reef on the windward side is partly fringed by a 10-fathom terrace. This terrace is widest within the broad re-entrants between reef projections. The exceptionally steep slopes off the leeward reef may indicate an unstable seaward reef growth into the generally quiet water in the lee of the atoll. At times of storms, particularly storms from the south-west, the edge of this reef may be broken away because of its instability, but the windward reef is not much affected because it is built directly against large swells which probably are able to break away unstable growths before they become very large. Examination of Fig. 1 shows that slump areas, in which the outer reef edge has broken away, are present on the leeward sides of three of the five atolls and on the windward side of none.

The outer slopes are also characterized by spurs which extend downward beyond projecting points of the reefs. North-west of Bikini, and connected by only a narrow neck, is a broad flat seamount

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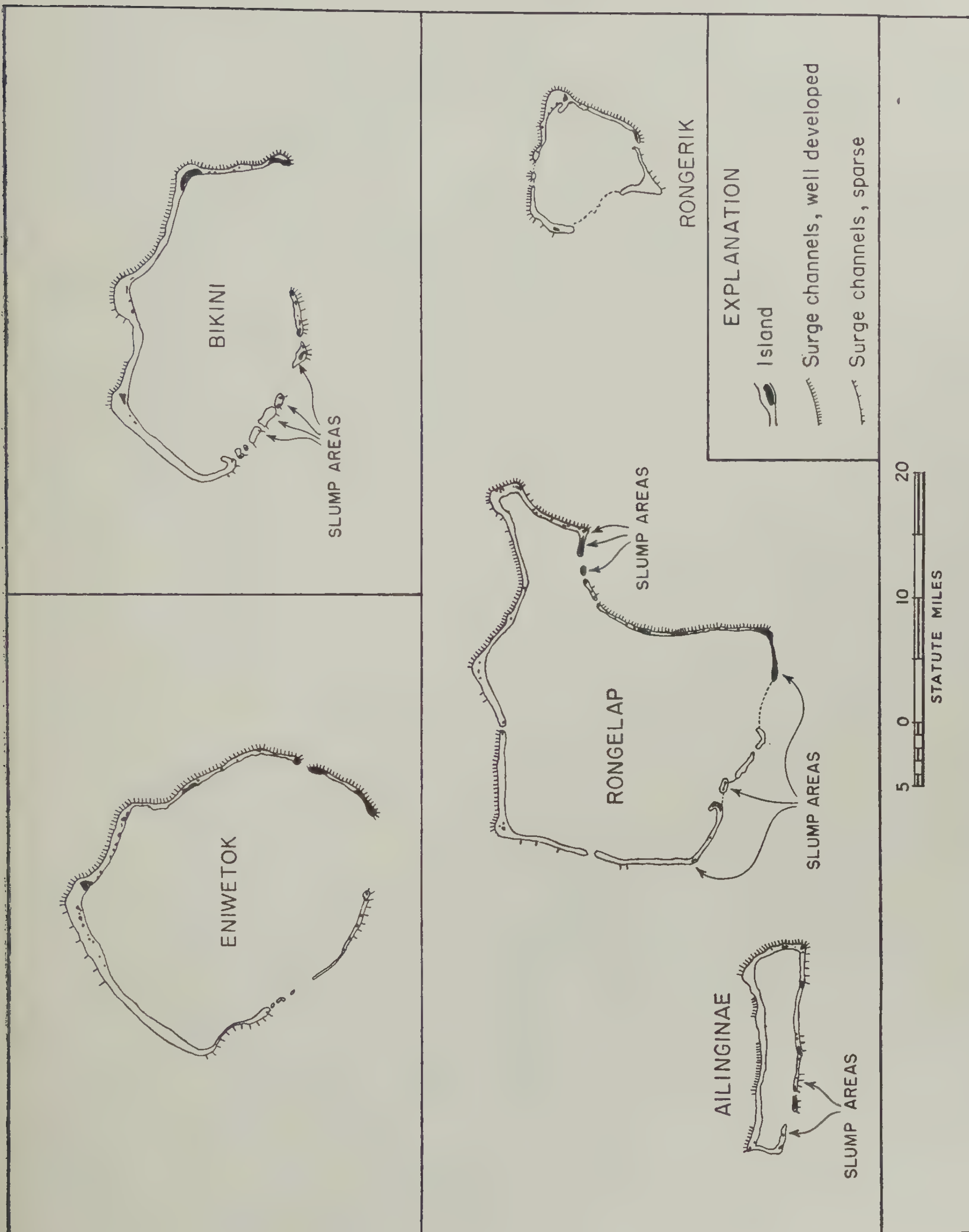

FIG. 1.—*Outline maps of five atolls in the northern Marshall Islands showing distribution of islands, surge channels, and slump areas.*

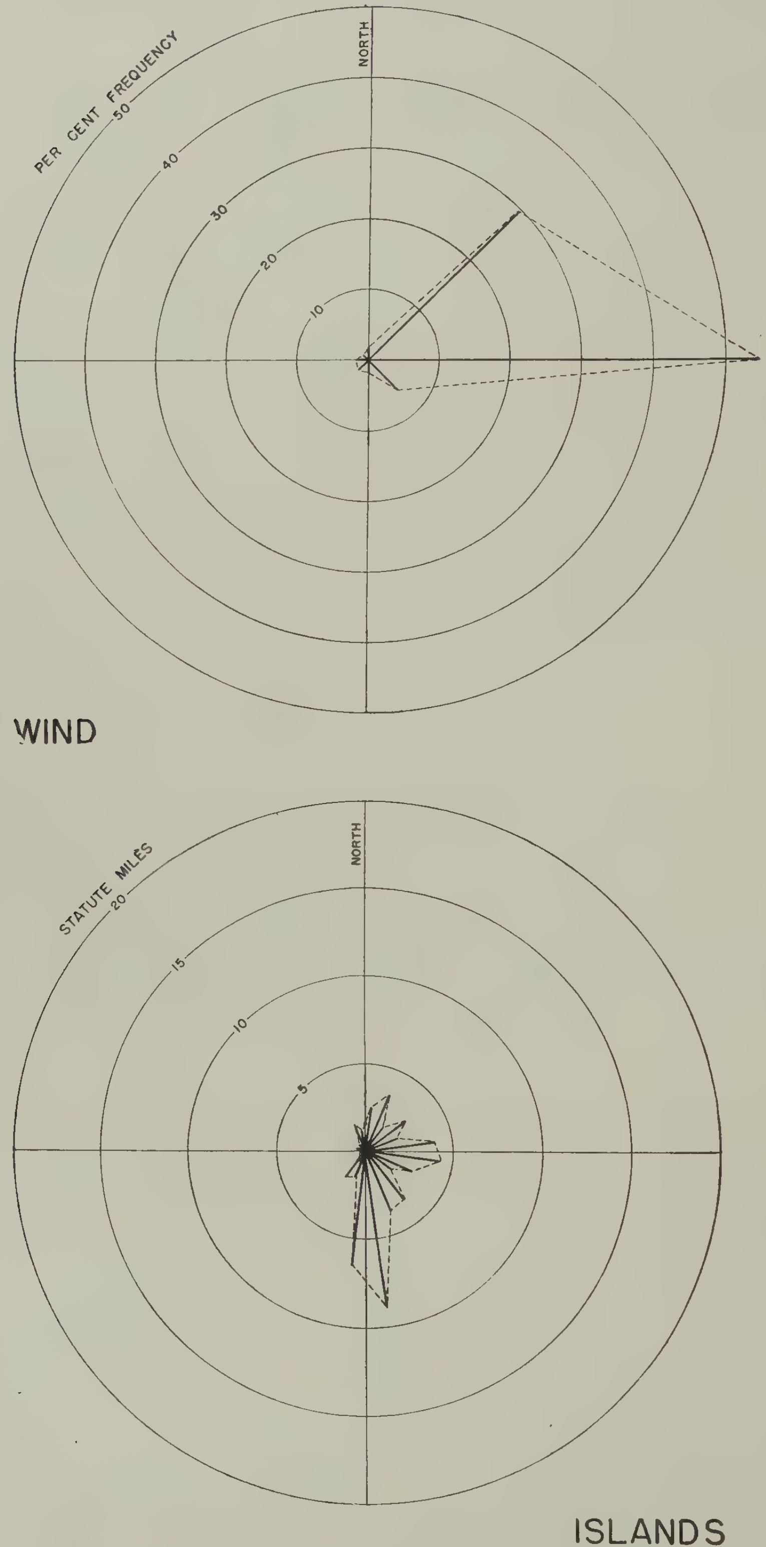

FIG. 2.—*Diagrams showing azimuth of wind and islands in parts of northern Marshall Islands.*

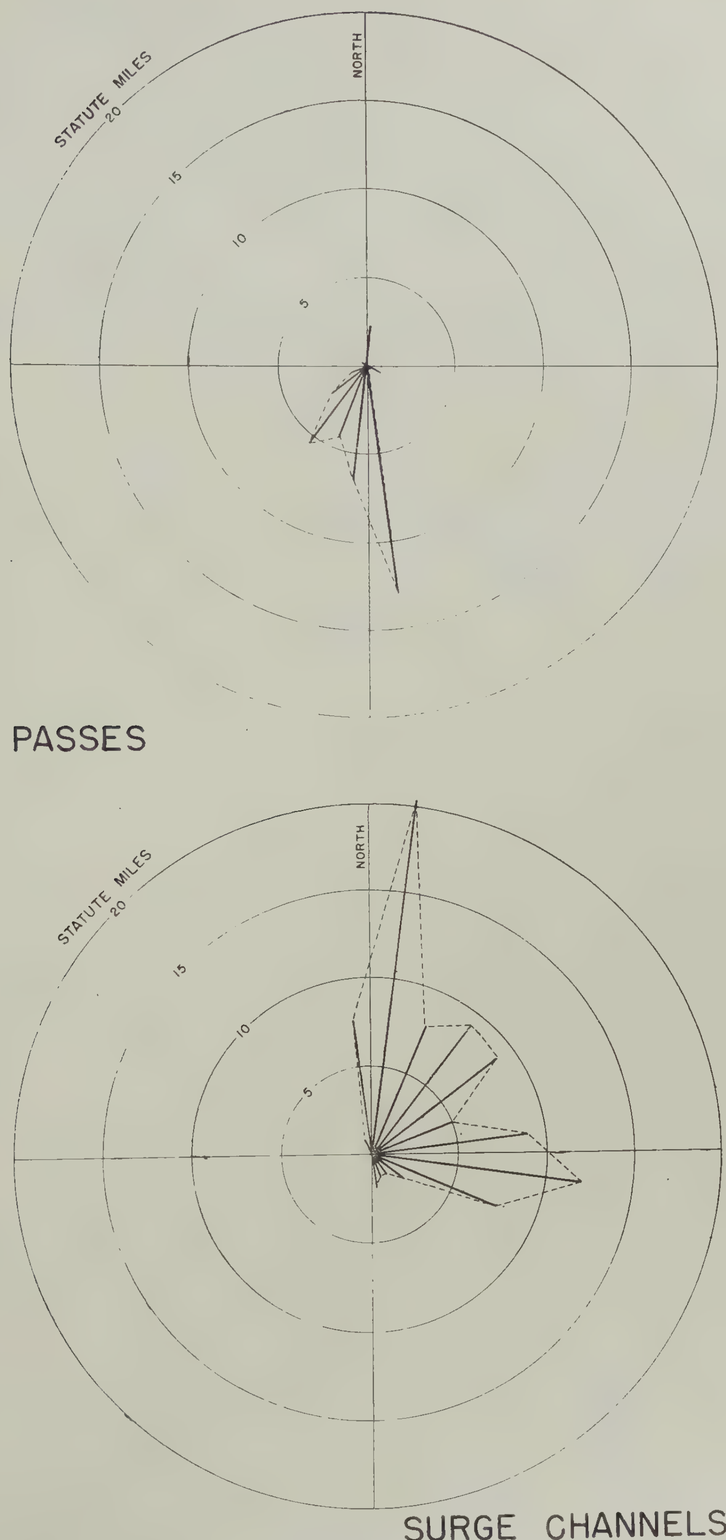

FIG. 3.—*Diagrams showing azimuth of passes and surge channels in parts of northern Marshall Islands.*

whose surface lies between depths of 700 and 850 fathoms. A large current eddy west of Bikini probably owes its presence to this seamount. A number of additional seamounts are present in the northern Marshalls. Fourteen of them are considered well surveyed and their shallowest depths range between 470 and 850 fathoms, averaging 690 fathoms. These seamounts are presumed to be volcanoes which have been bevelled by wave erosion at some period during the past.

Bottom samples from points shallower than 250 fathoms show that the upper part of the outer slopes is composed chiefly of blocks of reef rock (coral and *Lithothamnion*, a calcareous red alga) in a matrix of loose segments of *Halimeda* (a calcareous green alga) and foraminifera. This material grades to fine calcareous sand at about 600 fathoms. Samples from the top of the seamount adjacent to Bikini Atoll consist almost entirely of *Globigerina* sand. Sampling by earlier expeditions shows that the deep-sea floor is covered by *Globigerina* ooze grading laterally to red clay.

REEF AND ISLANDS

The subaerial part of the atolls is mainly a wide reef flat on which the islands are superimposed. The reef flat consists mostly of algal and coral limestone, large parts of which are veneered with foraminifera. The islands are composed of sandy debris overlying reef limestone. Living *Lithothamnion* with subordinate amounts of corals form a low ridge at the seaward edge of the reef. Cutting through this *Lithothamnion* ridge are numerous surge channels, usually about 5 feet wide, 15 feet deep, and 50 feet long. The main reefs are also penetrated by passes of varying depth and width but mostly large enough to allow the passage of ships.

A summary of the relationship of islands, surge channels, and passes to wind direction is given in Figs. 1 and 2. The diagram for wind in Fig. 2 was based on data accumulated over a period of 19 years at Ujelang Atoll. The length of each radial spoke indicates the annual percentage of time that the wind blows from that octant. The three other diagrams of Fig. 2 show the azimuth of islands, surge channels, and passes. For these diagrams, the direction of each spoke indicates the exposure in 15° steps. The exposure, or azimuth, is a line 90° from the trend of the local reef edge. The length of each spoke is a measure of the number of statute miles of islands, passes, or reef with surge channels having that azimuth and the length is measured parallel to the reef edge. The data for the three diagrams of reef features were compiled from measurements of all five atolls shown in Fig. 1. The diagram for islands exhibits a marked preference of the islands for the north-east and south-east quadrants, which are directly or nearly upwind. The one for passes shows a preference for the large reef openings to occur on the south side of the atolls, not directly up-wind or down-wind. The surge channel distribution bears the closest relationship to the wind diagram, although it is not identical in pattern because of the marked abundance of surge channels facing northward.

Some of the irregularities of the diagrams are due to the refraction of swell, and some probably are dependent on the general shapes of the atolls. The relationships that are present are in accordance with the suggestion that growth of *Lithothamnion* is most rapid in the zone of violent surf on the swellward side, thereby producing surge channels on that side. Similarly, where growth is most rapid, comminution is most rapid, producing debris which is carried across the reef and deposited as islands, which also are approximately on the swellward side. Slow growth of *Lithothamnion* of the south leeward side may result in failure to close up reef gaps, leaving them as passes.

Relationship to wind and swell direction is not confined to large reef features. Scattered along the centre of the reef, particularly on the windward side, are many small discontinuous sand bars. Nearly all of these bars have curved ends, which on the windward reef point toward the lagoon. Similarly, the sand pits at the ends of the windward islands also are curved and point toward the lagoon. On the leeward side also the reef has a few sand bars, but the tips of these show a less definite preferred direction. Prior to arrival at Bikini Atoll, study of the sand bars shown on aerial photographs suggested that the current flows lagoonward over the windward reef, and this deduction was later verified by current measurements. These measurements also showed that the indefinite character of the sand bars of the

leeward reef is undoubtedly due to reversals of current direction over that reef throughout the tidal cycle.

Locally, on the outer third of the reef are many nigger-heads. These appear to be blocks of reef material torn from the edge of the reef by the same storms that may have caused the slump areas. Although the storms might come from any direction, those from the leeward side are most apt to break off nigger-heads because those storms attack the most unstable part of the reef. Thus, the nigger-heads are commonest on the leeward reef though not restricted to it.

LAGOONS

Within the lagoon of each atoll the reef and islands are partly bordered by a shallow terrace which corresponds in depth to the 10-fathom terrace seaward of the reef. It is widest at points where the reef projects outward toward the sea. Within about a mile of the reef the lagoon terrace breaks into a slope extending to the 25 to 35 fathom depths found in most of the lagoons. Scattered about the lagoons are small steep coral knolls, some of which rise nearly to sea-level. The coral knolls are present in all of the lagoons studied and are most abundant in the eastward half of the smaller lagoons.

Samples and underwater photographs of the lagoon floors show that the foraminiferal sand of the island beaches usually extends only a few hundred feet from shore where it grades into fine and medium sand composed of comminuted remains of foraminifera, coral, *Lithothamnion*, and shells. The sand zone in all lagoons extends less than five miles from shore, from which it probably is derived. Beyond the sand zone, the lagoon is covered by bleached *Halimeda* debris, overlain by a patchy growth of living *Halimeda*. In the deeper atolls such as Eniwetok, the *Halimeda* debris merges into a foraminiferal sand at about 32 fathoms presumably because the depth is too great for active photosynthesis by *Halimeda*. These foraminifera, however, are different from those occurring in the shore zone. Corals in the lagoon occur mostly on the scattered knolls, but branching types occur on flat bottoms of intermediate depth.

GEOLOGICAL - GEOPHYSICAL - GEOCHEMICAL SIGNIFICANCE OF GEOSYNCLINES

By R. M. FIELD

U.S.A.

ABSTRACT

To be briefed by the case method illustrating the significance of:

(1) Evolution of the international concept of geosynclines from 1880 to 1948;

(2) Interrelation of paleontological, stratigraphical, dynamical, structural geomorphological and geophysical techniques.

Introduction.—Specific recent techniques not mentioned by M. F. Glaessner and C. Teichert in their excellent historical review, *American Journal of Science*, August, 1947.

Case illustration 1.—Correlation by paleontology along and across the strike of geosynclines as evidence of their growth and development. Appalachians, Wales, and Scottish Highlands.

Case illustration 2.—Paleogeography and mobility as demonstrated by the petrology of their contained sedimentary, igneous, and metamorphic rocks. Central Pennsylvania, Quebec and Wales.

Case illustration 3.—Marine geophysics of island arcs and submerged continental margins. East Indies, West Indies, east coast of North America.

Case illustration 4.—Concomitant intrusives and irruptives. Alpine, West Indian, Aleutian, Pre-Cambrian.

LES POSSIBILITÉS OFFERTES PAR LE "BATHYSCAPHE PICCARD—COSYNS" POUR LES ÉTUDES DE GÉOLOGIE SOUS-MARINE

Par C. FRANCIS-BOEUF

France

RÉSUMÉ

L'engin d'exploration sous-marin imaginé et réalisé par les Professeurs Piccard et Cosyns de l'Université Libre de Bruxelles (grâce aux subsides accordés par le fonds national de la recherche scientifique belge) doit, si de nouveaux retards ne se produisent pas, commencer sa campagne scientifique, dans le Golfe de Guinée, au début de l'automne 1948.

Ce sous-marin ou " bathyscaphe " est complètement indépendant du navire qui le conduit sur les lieux de plongée. Il peut s'approcher, et même se poser, sur le fond de la mer. Grâce aux hublots et aux projecteurs dont il est muni l'observation et la photographie des fonds sous-marins est possible. Deux moteurs électriques permettent d'explorer un itinéraire d'une vingtaine de milles. Enfin des engins extérieurs, ramasseurs de fond et carottiers, permettront de ramener des échantillons du sol sous-marin. Des renseignments concernant la géologie sous-marine devraient donc pouvoir être recueillis.

TENTATIVO DI INTERPRETAZIONE GENETICA DI CERTE ARGILLE APPENNINICHE ALLA LUCE DEI REPERTI OCEANOGRAFICI

By E. M. GALLITELLI
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ABSTRACT

In the Mediterranean Ophiolitic Formation, basic and ultrabasic rocks are frequently associated with more or less metamorphosed clays. In the Emilian Apennines, diabase, serpentine, etc., are generally associated with the polychromatic " argile scagliose." These have recently been shown to be associated with scarce and prevalently arenaceous foraminifera.

From affinities in facies between certain red clays and the diabases and from observations on the localised conversion to clay of diabase masses the following problems arise: (1) whether a genetical relationship between the ophiolites and the shaly clays can be shown experimentally, and (2) whether recent oceanographic researches showing comparable results lend support to (1).

P. Gallitelli has performed chemical analyses which show the close similarity between samples of the red clays and the diabases. Spectrographic analysis of the minor constituents seems to confirm this affinity.

Deductions as to palaeogeographical position can only follow an accurate comparison with present-day sedimentation. The most recent results in oceanographical research are examined and discussed. The data suggest that the deposit originated as a deep-water sediment. The possibility of the origin of part of the clay by submarine alteration of basic rocks appears to be supported by some of the work on present-day sedimentation.

PREMESSA

DA oltre un secolo é nota agli studiosi la così detta " formazione ofiolitifera " dell'Appennino settentrionale. Nel quadro della orogenesi mediterranea, essa può considerarsi parte della immensa cicatrice risultante dall'allineamento di rappresentanti simici lungo la cintura di pieghe che dai Pirenei, attraverso l'Appennino settentrionale e le Dinaridi, la parte interna della Penisola Balcanica, si allunga fino alla catena himalayana e all'arcipelago della Sonda.

Le vicende tettoniche e il diverso comportamento meccanico delle masse più o meno rigide, convogliate soprascorse e frammentate nel corrugamento, hanno ovunque portato come risultante una associazione straordinariamente complessa e spesso caotica dei più disparati elementi petrografici, eruttivi e sedimentari. Questo ha ostacolato e ostacola ovunque il lavoro di sintesi geologica, per ciò che riguarda i due principali problemi, dell'età e delle condizioni originarie di deposito della formazione.

Elementi comuni a tutta la cintura ofiolitica mediterranea sono rocce eruttive dei termini basici e ultrabasici-gabbri, diabasi, serpentine—sempre associati ad argille policrome più o meno metamorfosate fino a termini argilloscistosi veri e propri. Seguono diaspri e radiolariti, e, inglobati tettonicamente nella serie in misura varia, calcari venati privi o quasi di fossili, arenarie, marne argillose policrome analoghe a quelle tipiche " ofiolitifere," ecc.

Fino a che punto questi termini petrografici siano occasionalmente associati, e fino a che punto essi facciano parte integrante della serie, é difficile fino ad oggi stabilire. La sporadicità e la differente età dei fossili aggiungono difficoltà a difficoltà.

Così l'età rimane compresa fra limiti amplissimi—giura—creta superiore—e la facies é ancora oggetto di aspre discussioni, fra chi, come Steinmann, la ritiene abissale e chi non vuole accettare questo termine che sembra ancora urtare contro il concetto di orogene.

In questi ultimi anni ho voluto tentare lo studio della formazione, per ciò che riguarda l'Appennino settentrionale, da un punto di vista analitico. Tale criterio non era stato ancora tentato, mentre per oltre un secolo si erano susseguiti studi a carattere sintetico, interpretativo su base troppo superficiale.

Nell'Appennino, come é noto, il corpo fondamentale della formazione ofiolitifera é rappresentato da una imponente massa di argille, argille " scagliose " e argilloscisti associati a testimoni più o meno cospicui di rocce diabasiche e serpentinose. Secondo le moderne vedute, tale immensa massa eminentemente plastica si sarebbe riversata per scivolamento dalla zona ligure verso l'avanfossa padana, come mostra la vergenza statistica degli accartocciamenti verso nordest.

Trascurando per il momento tutti gli altri termini litologici associati in brandelli più o meno ridotti e per lo meno in parte convogliati tettonicamente nella serie, ho voluto prendere in esame il solo termine argilloso ofiolitifero, e ne ho iniziato lo studio sia dal punto di vista paleontologico (é da notare che tali argille dette " scagliose " per il loro notevole grado di metamorfosi erano considerate fino all'inizio di questa ricerca prive di microfossili) sia da quello paleogeografico.

Per quest'ultimo scopo si é resa indispensabile la conoscenza dei risultati delle indagini sulla sedimentazione recente. Non é infatti più possibile, allo stato delle nostre conoscenze, tenere avulsa l'indagine geologica, eminentemente interpretativa, dalla sua base naturale: tale base é data da tutte le notizie che ci vengono fornite sulle condizioni nelle quali oggi i diversi sedimenti marini si depositano e si associano.

I progressi degli studi sulla sedimentazione sono stati notevoli in questi ultimi anni (anche se rimane ancora enormenente da fare) ed hanno permesso di rivedere molti punti di vista accettati in precedenza come articoli di fede. Così, ad es., si é visto che la vecchia classificazione dei depositi marini quale era stata intesa dal Murray, risulta troppo rigida, in quanto le osservazioni talassografiche hanno mostrato che ciascuna regione presenta proprie caratteristiche in relazione a tutto un complesso di condizioni circostanti petrografiche, geofisiche, chimicofisiche.

Ho cercato pertanto di fornirmi di tutte le notizie possibili riportate dalle più recenti campagne talassografiche, e di vedere se e fino a qual punto il tentativo di interpretazione paleogeografica della roccia in esame può conciliarsi con i dati di fatto della sedimentazione attuale.

Naturalmente, impostando in questo modo la ricerca, non era più possibile limitare l'esame del sedimento argilloso allo studio micropaleontologico e a un esame macroscopico della roccia argillosa. Occorreva spingere a fondo l'indagine mineralogica e petrografica del materiale. E a questo scopo si é aggiunta la collaborazione di P. Gallitelli, che ha iniziato lo studio analitico petrografico dal punto di vista sperimentale e di cui nelle pagine seguenti verranno riportati i risultati fino ad ora raggiunti. Nelle pagine che seguono sarò costretta per chiarezza a riassumere in parte dati già pubblicati.

La ricerca iniziata non vuole rappresentare al momento niente altro che un " tentativo " di metodo strettamente analitico di confronto fra un sedimento " litificato " e i sedimenti attuali.

La lunga parentesi bellica e postbellica ha paralizzato per molti anni lo scambio di materiale bibliografico. E'comprensibile quindi la grande quantità di lacune che rimangono ancora aperte.

Desidero tuttavia rivolgere il mio più caldo ringraziamento a tutti gli studiosi che in questi ultimi mesi, sia con la collaborazione, sia con l'invio di memorie originali, notizie e consigli hanno reso possibile l'inizio del lavoro. Primo fra tutti, ringrazio mio marito P. Gallitelli per essersi assunto il difficile studio analitico, spettrografico, roentgenografico dell'argilla e dei suoi rapporti con la roccia diabasica associata. Desidero inoltre ricordare con profonda riconoscenza il dr. ph. H. Kuenen dell' Università di Groningen, la dott. Ir. G. A. Neeb per l'invio della relazione della spedizione " Snellius "; i professori Parker D. Trask, F. P. Shepard, H. C. Stetson, J. A. Cushman, H. T. Sverdrup, per avere aderito cortesemente con invio di pubblicazioni, di indicazioni e di consigli alle mie richieste. Senza il loro cortese interessamento non sarebbe stato possibile nemmeno l'inizio della presente ricerca.

IMPOSTAZIONE DELLA RICERCA E RISULTATI PALEONTOLOGICI

Dato il carattere della presente nota, credo superfluo fare qui una rassegna della ponderosa bibliografia riguardante la formazione ofiolitica in genere, e quella appenninica in particolare. Basti qui dire che, data la estrema scarsità di macrofossili in tutti i termini di questa formazione appenninica, e data la mancanza, fino a pochi anni fa, di concreti esami micropaleontologici, tutte le sintesi geologiche risultano finora basate prevalentemente sull'elemento tettonico. Ne venne quel susseguirsi di ipotesi

e di discussioni che é a tutti noto, e che fatalmente si continuerà fino a che una cospicua serie di documentazioni non avrà posto più solida base per il lavoro interpretativo.

Fu appunto con questo intento che nel 1942 iniziai il prelevamento e lo studio di campioni di argilla. Rimando per più ampie notizie ai lavori già pubblicati.

Fra i vari componenti litologici della formazione, ricordati dianzi, scelsi non a caso l'argilla ofiolitifera. Essa costituisce infatti il corpo principale non solo della grande copertura alloctona appenninica, ma di gran parte della cintura ofiolitica mediterranea. Tutto l'altro materiale petrografico sopra ricordato-e che ha procurato finora gli sporadici fossili-non può sicuramente ritenersi coevo alla massa argillosa ofiolitifera. Non é infatti escluso che una parte almeno di questi materiali sia stata convogliata, frantumata e inglobata come ospite occasionale nella massa argilloscistosa durante lo scivolamento. Vediamo infatti che, specialmente nel versante padano e nella media montagna, queste rocce appaiono ridotte a brandelli o lenti incastonati senz'ordine nella massa argilloscistosa.

DEDUZIONI CRONOLOGICHE

Le " argille scagliose " propriamente dette, cioé quelle che sorreggono e involgono le masse ofiolitiche, erano ritenute prive di microfossili. Contengono invece evidenti e abbondanti microfaune certi lembi anche estesi di marne argillose analoghe per aspetto alle " scagliose," che si ritengono inglobate tettonicamente in esse e che risultano di età paleogenica.

Nel prelevare i miei campioni evitai naturalmente queste lenti, e raccolsi soltanto il materiale tipico, posto a contatto con masse ofiolitiche.

Dal trattamento dell'argilla prelevata in diverse località, venne messo in evidenza che i fossili sono presenti prevalentemente nei lembi argillosi di color rosso-bruno, mentre non sono ancora stati riscontrati nelle argille grigie. Venne determinata una faunetta di microforaminiferi, di cui é stata già pubblicata l'illustrazione. Qui mi limito a ricordare i risultati principali.

Delle 38 diverse specie e varietà riconosciute complessivamente, il maggior numero é rappresentato da forme arenacee. Soltanto 6 sono calcaree, rappresentate da scarsissimi individui, di dimensioni minime, quali ad es. *Gümbelina globulosa* (Ehrb.) di mm. 0,07. La maggior parte delle specie trovasi indifferentemente nella Creta e nel Paleogene; alcune addirittura si continuano fino all'attualità; 5 non sono determinabili specificamente, 6 sono forme nuove per la Scienza.

Delle rimanenti, 8 (*Psammosphaera rhumbleri* (Franke), *Pelosina complanata* (Franke), *Haplostiche dentalinoides* Reuss, *Spiroplectoides clotho* (Grzibowsky), *Gümbelina globulosa* (Ehr.), *Rotalia* (*Gyroidina*?) *micheliniana* (d'Orb.), *Globigerina cretacea* (d'Orb.), *Anomalina sp. af. lorneyana* (d'Orb.) di cui in-erte solo la 3 e l'ultima qui elencate, sono cratacee. Rimane una forma sola che determinai nel 1942 come *Cyclammina acutidorsata* Hantken, e che sarebbe esclusiva del paleogene. Ma di questa forma—determinata senza sufficiente bibliografia durante gli anni di guerra—é in corso lo studio di revisione, sulla base di topotipi ungheresi inviatimi in queste ultime settimane dal Geologische Bundesanstalt di Vienna, topotipi che risultano non corrispondere del tutto agli esemplari delle " argille scagliose."

In conclusione, malgrado la presenza di alcune forme cretacee, non é ancora raggiunto un risultato concreto sull'età del deposito, il cui accumulo può anche essersi verificato con grande lentezza, attraverso un lungo lasso di tempo geologico. E' tuttavia soddisfacente il fatto dimostrato, che le argille contengono microfossili, e che questo campo nuovo di indagine paleontologica potrà certamente essere in avvenire sfruttato con risultati concreti.

DEDUZIONI PALEOGEOGRAFICHE

Assai piu evidenti sono risultati dalla fauna—e dai caratteri petrografici dell'argilla, come sarà discusso nelle pagine seguenti—i caratteri paleogeografici del deposito.

I fossili costituiscono una rarità nell'argilla, il cui residuo sabbioso si può ritenere inferiore al 2%. Lo stato di conservazione dei fossili (mi riferisco a quelli meno piccoli) risente delle azioni dinamiche che metamorfosarono la massa argillosa durante lo scivolamento. Tuttavia, é da escludere

un rimaneggiamento, in quanto i gusci sono costantemente obliterati e impregnati di particelle finissime di argilla rossa. Mancano quasi completamente i radiolari, di cui si é trovato qualche esemplare indeterminabile.

L'argilla ha una percentuale scarsissima di carbonato di calcio (1,60-1,54%).

I microforaminiferi sono prevalentemente di dimensioni minime e. tolti pochi esemplari, sono tutti arenacei, a elementi silicei, come prova la loro insolubilità in HCl diluito a caldo.

Non avendo a disposizione le relazioni zoologiche delle più recenti spedizioni talassografiche Meteor e Snellius, eseguii un esame comparativo con la batimetria riportata per le forme dragate dalla spedizione Challenger. Cercai di controllare in quali condizioni di profondità e di fondo furono trovate dal Challenger associazioni faunistiche del tipo di quella in esame. Riporto qui brevenente i dati emersi:

(1) *Tutte* le associazioni di forme quasi esclusivamente arenacee provengono da una profondità media di 3.000-5.500 metri, in alcuni casi da 7.000 metri;

(2) le microfaune arenacee (associate a volte a qualche sporadico miliolide con guscio ridotto a un velo siliceo) sono quelle che in molti casi hanno rappresentato l'unica testimonianza di vita nei dragaggi più profondi;

(3) tutti i più profondi dragaggi di tipi arenacei hanno estratto un fondo di argilla finissima rossa;

(4) le stesse associazioni possono tuttavia coesistere anche in fondi fangosi (green mud, red mud, grey mud) nei quali cioé l'argilla non é più pura, ma verosimilmente fangosa.*

Da tutto quanto esposto riassuntivamente sopra, ho creduto di poter dedurre, per i campioni di argilla scagliosa rossa da me prelevati in punti diversi della formazione ofiolitifera, che essi sembrano rappresentare un deposito formatosi a notevole profondità.

PROBABILE RAPPORTO GENETICO ARGILLA ROSSA—DIABASE

Si é detto che alle argille scagliose sono associati quasi ovunque testimoni di rocce ofiolitiche, in particolare diabasi e serpentine.

Nel corso delle numerose escursioni effettuate nella media montagna modenese per il prelevamento di campioni, mi colpí sempre una singolare rassomiglianza cromatica fra l'argilla scagliosa e le masse ofiolitiche appenniniche. Nel 1947, durante una gita all'affioramento diabasico di Rossena (Reggio E.) ebbi modo di osservare lingue di diabase disfatte anche in profondità, e ridotte a una poltiglia argillosa simile in tutto, almeno in apparenza, alla tipica " argilla scagliosa " rossa. L'osservazione poté ripetersi in altri affioramenti diabasici appenninici, come ad es. in quello notevole di Boccassuolo (Modena).

Tuttó questo mi portò a formulare i seguenti problemi. Esiste, ed é documentabile sperimentalmente, una relazione genetica fra le ofioliti e una parte almeno degli argilloscisti? Si deve ritenere lo smembramento ofiolitico come fatto di alterazione meteorica, subaerea, o vi sono dati per pensare a una originaria trasformazione subacquea delle rocce basiche? Esiste qualche elemento comparativo apprezzabile offertó dalle attuali conoscenze oceanografiche? La letteratura offre una quantità di esempi di tali trasformazioni di rocce ofiolitiche. E' sintomatico inoltre il fatto, già ricordato più volte, della costante associazione di argille più o meno metamorfosate a rocce basiche e ultrabasiche nella cintura ofiolitica mediterranea.

Venne così intrapresa, per opera di P. Gallitelli, una serie di prove sperimentali, di analisi chimiche e di esami petrografici allo scopo di vedere se e fino a qual punto tale ipotesi possa trovare una base.

Data la vastità della ricerca sono stati per il momento presi in considerazione prevalentemente i rapporti fra campioni di argilla rossa e di diabase, le due rocce, cioé, che con maggiore evidenza si sono prestate a questa prima ricerca.

Tutti i dati parziali finora ottenuti sono presentati da P. Gallitelli in altra sede della presente sessione del Congresso Internazionale Geologico. Mi limito qui a riportare i dati conclusivi.

*La (4) spiega quindi l'analogia di habitus faunistico fra " argille ofiolitifere " e red beds inglobati tettonicamente nelle argille stesse.

(1) *Analisi chimiche.*—Analisi sono state eseguite sia sul diabase di Rossena, sia sul suo prodotto tout-venant di disfacimento, sia sul prodotto argilloso ultimo in situ. E' interessante, che il punto rappresentativo del diagramma di Niggli cade per quest'ultimo prodotto—sicuramente derivato in situ dal diabase—in pieno campo dei sedimenti argillosi, mentre per il prodotto tout-venant trovasi al margine fra il campo eruttivo e quello sedimentario, e per il diabase in pieno campo eruttivo.

Altre analisi sono state eseguite sui campioni di argilla scagliosa rossa—distante attualmente circa 19 Km. da afforamenti diabasici –contenente microforaminiferi arenacei. I risultati mostrano ugualmente stretta analogia con quelli ottenuti dalle analisi di rocce diabasiche, se si prescinde: (*a*) dal maggior contenuto in CaO e Na_2O nella roccia diabasica, imputabile alla presenza del plagioclasio e dei suoi prodotti di alterazione ancora contenuti nella roccia; (*b*) dal maggior contenuto in K_2O nelle argille rispetto al diabase, imputabile al potere adsorbente di queste verso gli ioni dotati di grande raggio.

(2) *Esperienze sotto pressione ed esami roentgenografici.*—L'argillificazione del diabase, già osservata in natura, si può compiere anche in laboratorio. Esperienze eseguite a temperatura ordinaria e a temperatura elevata (220°-250°) e sotto pressione (180-220 atm.) hanno messo in evidenza che dalla polvere di diabase può ottenersi un materiale plastico, di aspetto argilloso, che all'esame roentgenografico risulta nella sua parte più fine (diam. $< 1\mu$) caolinicoillitico—ottimamente visibile dalle nette interferenze—come la parte più fine delle argille della formazione argilloso-ofiolitifera appenninica.

(3) *Esami spettrografici.*–Tra i costituenti minori delle argille della formazione ofiolitifera, alcuni più rari, come Sc e Yb, legati a minerali di magnesio e caratteristici di rocce basiche, sono presenti nel diabase, nel suo prodotto di disfacimento e nelle argille scagliose ofiolitifere grigie e rosse (queste ultime fossilifere). Mancano invece in una argilla pliocenica da comune dilavamento subaereo, presa per confronto. Ciò fa pensare che le argille di questa formazione contengano i prodotti del disfacimento delle rocce diabasiche di cui rimangono i testimoni, e dalle quali avrebbero ereditato questi caratteristici costituenti minori.

FACIES E GENESI DELL'ARGILLA IN RAPPORTO ALLA SEDIMENTAZIONE RECENTE

Lo studio analitico dei campioni di argilla rossa ha dunque offerto i seguenti dati.

(1) L'argilla contiene fossili, e precisamente microforaminiferi quasi totalmentearenacei, associazioni analoghe a quelle che costituiscono l'unica microfauna attuale di notevoli profondità, e che pure attualmente si trova in sedimento argilloso o argillomarnoso.

(2) La roccia argillosa risulta all'analisi una argilla pressapoco pura, con un residuo sabbioso inferiore al 2% costituito da granuli di dimensioni ridotte (mm. 0,08-0,16) in cui compaiono quarzo, mica biotite, muscovite, plagioclasio geminato secondo l'albite, ortose.

(3) L'argilla mostra all'analisi chimica una stretta analogia con campioni di diabase della stessa formazione appenninica.

(4) Campioni di un diabase, del suo prodotto di disfacimento tout-venant, e di un ultimo prodotto melmoso di aspetto simile all'argilla, prelevati in situ, hanno mostrato, a parte una ovvia analogia chimica, la posizione rappresentativa nel diagramma tetraedrico di Niggli, rispettivamente nel campo delle rocce eruttive, al limite tra queste e le rocce sedimentarie, e nel campo di queste ultime.

(5) Il diabase e le argille in esame contengono fra gli elementi rari Sc e Yb, che mancano invece in un' argilla tipica marnosa di origine sicuramente terrigena, presa per confronto.

(6) Esperienze sotto pressione accompagnate da esami roentgenografici mostrano che dal diabase si ottiene un prodotto argilloso in cui compaiono caolinite e minerali illitici, analogamente a quanto risulta dall'esame roentgenografico delle argille rosse fossilifere.

In una nota preliminare pubblicata nel 1943, avevo osservato: " i depositi argillosi rossi dei grandi fondi attuali sono considerati anche dalla oceonografia fisica attuale . . . come derivati da decomposizione di rocce eruttive basiche, come già Murray e Wyville Thomson avevano supposto . . . " L'aggiornamento bibliografico mi permette di rivedere ora questo punto di vista almeno inteso in senso così generale.

Le moderne ricerche hanno mostrato che la percentuale di carbonato di calcio nei sedimenti é in funzione della presenza di O e di CO_2 nelle acque marine. In altre parole la scarsità di carbonato di calcio nei sedimenti (e quindi anche nelle argille rosse) sarabbe secondaria. La presenza di correnti—ed anche, secondo Kuenen, la presenza di vulcani sottomarini—può considerarsi fattore determinante di depositi poveri di calcare indipendentemente dalla profondità. D'altra parte, poiché pressione e bassa temperatura agiscono in senso favorevole per la soluzione di carbonato di calcio, ne viene che a grande profondità la dissoluzione da calcare é possibile su più larga scala.

Quanto poi alle argille rosse in particolare (le quali effettivamente sono localizzate nei grandi fondi) Correns e Mehmel, sulla base di materiali raccolti durante la spedizione del "Meteor", hanno eseguito analisi microscopiche e roentgenografiche sia su argille rosse, sia sulla parte argillosa di fanghi bleu e di fanghi a Globigerina. I reperti mostrano che non vi é differenza nella natura dei minerali argillosi, in quanto essi sono in tutti i campioni—sia pure in diverse proporzioni—halloisite, montmorillonite, caolinite. Per questa ragione—oltreché per la presenza di granuli di quarzo e mica di origine terrigena—gli Aa. attribuiscono una origine *prevalentemente* terrigena alle argille rosse, analogamente ai fanghi bleu e alla parte argillosa dei fanghi a Globigerine. Correns poi deduce, dalla somilgianza della composizione meccanica e della composizione dei minerali argillosi in un campione di argilla rossa lungo cm. 86, che mica, halloisite e montmorillonite *non compaiono come minerali secondari nelle argille rosse.*

Fra i materiali dragati dalla spedizione "Snellius," pochissimi campioni di argille rosse sono stati esaminati. Ir. G. A. Neeb condivide l'opinione di Correns; non sono tuttavia presentati risultati di esami roentgenografici o spettrografici di argille rosse. Inoltre, malgrado la tendenza ad accettare la comune origine di questi sedimenti, l'autrice mantiene distinto nella sua classificazione dei sedimenti il termine "red clay". Inoltre, là ove definisce i fanghi vulcanici (pag. 8), osserva che "There may also be material washed off from recent submarine volcanoes . . . In the latter cases lava flows which extend into the sea may be eroded." Questo conferma la possibilità (pur senza che vengano portati in campo dati più concreti) che materiali eruttivi basici possano essere alterati ed erosi in ambiente sottomarino. E se si considera la grande area occupata da effusioni basiche sottomarine, non é possibile pensare che—sia pure con una alterazione più lenta nel tempo di quanto non avvenga per il dilavamento subaereo—tali masse basiche non vengano in parte modificate in una forma argillosa.

Un dato più concreto in questo senso é offerto dal lavoro di M. N. Bramlette e W. H. Bradley su materiali di mare profondo dragati nell'Oceano Atlantico settentrionale fra Terranova e l'Irlanda dal piroscafo "Lord Kelvin" nel 1936. Le carote (cores) hanno una lunghezza di metri 0.34-2,97; la profondità alla quale vennero prelevate va dai 1.280 metri ai 4.820 metri. Interessame per il nostro caso due carote, n. 10 (lunghezza metri 2,97) e n. 11 (lunghezza metri 0,34) prelevate rispettivamente a metri 4.190 e 4.820 di profondità. Uno spessore superiore di 15 cm. é dato da fango a Globigerina, che si adagia sopra e dentro cavità irregolari dell'area superiore di una roccia argillosa. "This clayey rock grades downward through closely similar rock that is strongly impregnated with manganese oxide and that contains nodular lumps of much altered basalt . . . The lower part of this core described in some detail because it suggests that the material represented an altered rock which may be a submarine lava flow, though the evidence is inadequate and additional cores in that area are necessary to test this possibility . . .".

Il sedimento della carota 10 differisce dagli altri per il carattere eminentemente argilloso del fango. Esso é definito come un fango basaltico. La parte superiore contiene poco materiale clastico (quarzo) e pochi comuni foraminiferi pelagici e bentonici; inferiormente essi divengono sempre più rari e virtualmente assenti. Un campione di fango basaltico é stato analizzato nel laboratorio chimico del Geological Survey da E.T. Erickson. "The analysis of this basaltic mud is not much like those of the common sediments, shale, mudstone, or clay; nor, on the other hand, is it like the analyses of basalt. *It is surprisingly similar, however, to the analysis of a large group of oceanic red clays*, despite the fact that the basaltic mud is quite unlike the red clays in appearance and mineral composition." Nella

tabella n. 7 (pag. 33) sono riportate le analisi di un campione del fango basaltico in parola e di due campioni di argille rosse oceaniche. I risultati sono analoghi a quelli da noi ottenuti dall'analisi dell'argilla rossa appenninica e da quelle di campioni di diabasi. Gli Aa. concludono: " It is perhaps futile to speculate further upon the possible origin of the volcanic muds in core 10. Nevertheless, the basaltic composition, the restriction to core 10, and the fact that the upper mud zone has at least approximately, the same stratigraphic position as the volcanic rock in core 11 suggests a genetic relationship with deeply altered volcanic rock like that found in core 11." "A submarine volcanic eruption, perhaps in the vicinity of core 11, may have discharged into the sea finely divided basaltic particles and at the same time have thrown into suspension much clay, derived largely from the deeply altered surface of earlier submarine lava flows." "Additional cores in the part of the North Atlantic where cores 10, 11, and 12 were taken should prove to be of exceptional interest, for it is only in this way that submarine volcanic activity and its extent can be definitely established."

Fino a qual punto, infatti, tali aree vulcaniche e tali fatti di alterazione subaquea di rocce basiche siano estesi, non é possibile dire. Tuttavia, i reperti sopra citati su sedimenti recenti confermano quanto é risultato finora dall'inizio di un più complesso studio analitico di sedimenti " litificati." In altre parole, se la prosecuzione della ricerca in corso non porterà dati in contrario, si può ritenere che i campioni di argille scagliose rosse appenniniche studiati siano derivati per la massima parte (data la scarsità di residuo quarzoso, clastico) da alterazione di una roccia diabasica, a notevole profondità. Di più, la presenza dei microfossili sta a provare che tale alterazione avvenne—come nel caso rilevato da Bramlette e Bradley, e ammesso in via generale da G. A. Neeb e altri—in ambiente sottomarino. In tal caso, dunque, la virtuale assenza di $CaCO_3$ non sarebbe da ritenersi secondaria (dovuta cioé a dissoluzione per presenza di CO_2 ad opera di correnti e di vulcani) ma originaria.

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DISCUSSION

S. VAN DER HEIDE asked the author: " Hanno questi foraminiferi chei lei ha trovato negli argilloscisti qualche valore stratigrafico? "

E. M. GALLITELLI replied: " Fra i microforaminiferi riconosciuti nelle argille ofiolitifere compaiono sei forme sicuramente sopracretacea. Precisa che tuttavia è opportuno portare ulteriori contributi per risolvere il problema della eta di tali argille. È comunque dimostrato per la prima volta, nella presente ricerca, che *è possibile* trovare in avvenire nelle argille ofiolitifere concreti documenti per lo studio stratigrafico della formazione."

MECHANICAL COMPOSITION OF MARINE SEDIMENTS AS INDICATIVE OF THE CONDITIONS OF DEPOSITION

By M. V. KLENOVA

U.S.S.R.

ABSTRACT

1. In research work on marine geology in the U.S.S.R. much attention was devoted to the standardization of analytical methods and classification of recent sediments.

In mechanical analyses of recent sediments the decantation method is used, with control of grain size under the microscope.

2. The classification of sediments according to size composition is based on the content of the grade less than 0.01 mm. reflecting the effect of hydro-dynamical conditions and determining the character of the physical properties of the sediment and especially of the process of sedimentation. An idea was developed of the types of mechanical composition and the distribution of sediments in relation to bottom topography.

3. Typical cases of sediment distribution are confirmed by many thousands of mechanical analyses. The pattern of distribution remains uniform over wide areas of sea-bottom, being remarkably constant in submarine depressions of the open sea.

4. The examination of histogams shows that one-peaked graphs correspond to stable hydrodynamical conditions. Double-peaked graphs indicate regions subject to erosion and are characteristic of a lack of balance between hydrodynamical conditions and the composition of the sediment.

5. The degree of dispersity of the sediment determines its mineral and chemical composition and physical chemical processes, for the gradual disintegration of rock assists the passing into a chemically active state of new atoms bound in solid structures of the primary mineral material.

6. The distribution of sediments on the sea floor allows the concept of a general hydrodynamical activity, by which is understood the whole complex of water movements generated by constant, tidal and drift currents and swell. This value is determinative of all processes occurring in the sea.

DRILLING ON BIKINI ATOLL, MARSHALL ISLANDS *

By H. S. LADD, J. I. TRACEY, GORDON LILL, J. W. WELLS and W. S. COLE

U.S.A.

ABSTRACT

During a resurvey of Bikini Atoll (Operation Crossroads) in the summer of 1947, five holes were drilled on Bikini Island. One hole located on the seaward side of the island was drilled to 300 feet, three others on the lagoon side to 190, 1,346, and 2,556 feet, and the fifth, at the south end of the island, to 118 feet. Core recovery was fair above 300 feet but very poor at greater depth. Cuttings were collected at 5- to 10-foot intervals.

No materials other than calcareous sediments—beach rock, reef limestone, coral rubble, and sand—were encountered. Beach rock was found between tide levels; at depths of 35 to 65 feet below low tide, the presence of a zone of hard limestone suggests that the shallow terraces fringing the existing reef continue beneath the island; below 500 to 600 feet the section consists of unconsolidated or very poorly consolidated calcareous sand with a few thin streaks of firmer material. Abundant molds of corals and mollusks at depths of 170 to 575 feet suggest that this part of the section was above sea level for some time after deposition.

Preliminary studies of corals and mollusks show that late Tertiary rocks were encountered at 930 feet and the top of the Tertiary may be considerably higher. Larger foraminifera from 1,305 to 1,923 feet indicate an horizon well down in the Miocene, probably lower Aquitanian. *Miogypsina* was found first at 1,020 feet.

The Bikini section differs markedly from that of Funafuti, Ellice Islands, where hard dolomitic limestone apparently post-Tertiary in age was found at 748 feet and extended to the bottom of the hole at 1,114 feet.

INTRODUCTION

DURING the Bikini Scientific Resurvey (Operation Crossroads) in the summer of 1947, five holes were drilled on Bikini Island (Fig. 1). One of these (No. 2B) was completed to 2,556 feet (778·5 meters)—the deepest hole yet drilled on a Pacific coral island. Only calcareous sediments were encountered, most of them unconsolidated or very poorly cemented. Tertiary rocks have been identified from 935 feet (284·3 meters) but the top of this system may be considerably higher. A brief description of drilling operations, a preliminary statement of results, and comparison with other Pacific island drill-holes are given below.

DRILLING OPERATIONS

All drilling equipment and drilling crews were furnished by the Geo. E. Failing Supply Company under contract with the Navy Department. The drill was the " 1,500 Holemaster " rotary type, mounted on a truck and complete with all necessary tools and equipment, including about 2,500 feet of drill stem. Rock bits were used for straight drilling and hard metal bits for coring. After setting 6-inch surface casing, the holes were continued with $5\frac{7}{8}$ inch bits. In the deepest hole (No. 2B), 4-inch casing was set to a depth of 804 feet, the remainder of the hole being drilled with a $2\frac{7}{8}$ inch rock bit. Salt water was used with salt-water mud at the beginning of the operation but proved unsatisfactory. During the drilling of the deep hole, fresh water and fresh-water mud were substituted.

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*This paper, which presents results of research carried out for the Bureau of Ships and the Office of Naval Research, Navy Department, in co-operation with the Office of the Chief of Engineers, Department of the Army, is published by permission of the Director, U.S. Geological Survey.

Expenses of the drilling were supported by the Bureau of Ships and formed part of the geological work of the Bikini Scientific Resurvey. The scientific work was supported by funds provided by the Office of Naval Research and the Military Intelligence Division, Office of the Chief of Engineers. The 1947 operation was carried out under the leadership of Capt. C. L. Engleman, Project Officer. The writers wish to thank Capt. Engleman for enthusiastic co-operation in solving the many drilling difficulties as they arose. They are also indebted to Cdr. Roger Revelle, head of the Geophysics Branch, Office of Naval Research, for encouragement and support in planning and carrying out the entire program.

V. C. Mickle, assisted by Emmett Alexander, was in charge of two drilling crews of three each, and the drill was operated continuously in 12-hour shifts. A geologist was on duty at all times.

As originally outlined, the drilling program called for a series of five holes, three to windward across Bikini Island and its reef, and two to leeward on opposite sides of one of the small south-western islands. These holes were to be cored continuously to 300 feet and one of them carried by rock bit to 2,500 feet. When the first holes were put down, the core recovery was poor and the consumption of mud so great that changes seemed in order. The plan to drill on the cavernous reef flat was abandoned, and efforts were concentrated on completing the deep hole with as many core runs as time would permit.

Core recovery was excellent in hard limestone and sometimes good in the sand. It was poorest in loose or weakly consolidated material in which hard coral heads were scattered in a matrix of loose material. In the deepest hole no coring was done, but in Hole No. 2A, carried to 1,346 feet (410 meters), 271 feet were cored with a recovery of 41 feet (15·1%). Cuttings were recovered at 5 to 10 foot intervals from all five holes.

There was an appreciable loss of drilling mud during all drilling, and, on occasion, cavities were encountered that completely stopped circulation. One such cavity was cemented and leakage at lower levels controlled by various expedients such as pouring a variety of materials, including rice hulls, sawdust, and corn meal, in the hole. Between 2,000 and 2,500 gallons of fresh water were used in each 24-hour period during the drilling of the deepest hole.

All cores and cuttings are on deposit at the United States National Museum in Washington, D.C. Except for a few samples particularly rich in larger fossils, each is being split into two equal parts, one for study, the other to be retained intact.

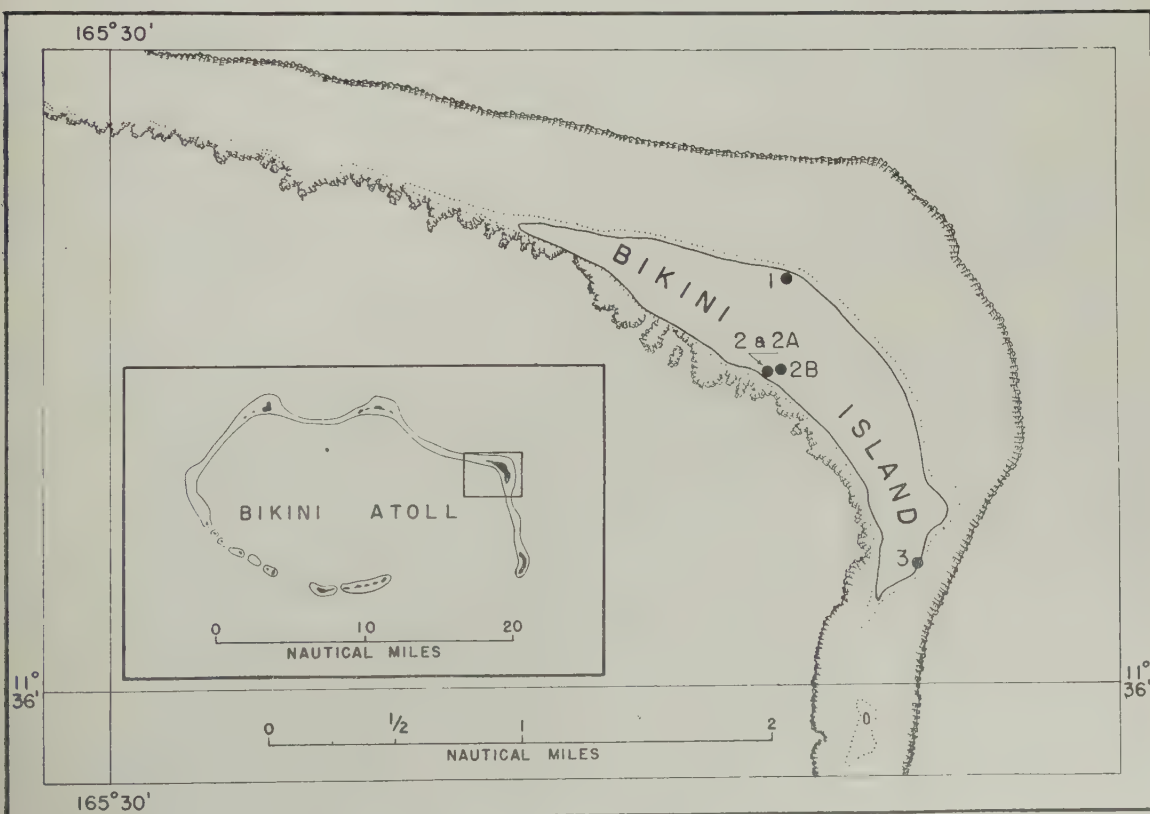

FIG. 1.

GEOLOGY

Lithology.—Preliminary studies of the cores and cuttings reveal the following generalized lithologic zones:

(1) Unconsolidated calcareous sand and gravel from the surface to a level immediately below high tide.

(2) Bedded calcareous sandstone and conglomerate 2 feet or more in thickness at intertidal levels (beach sandstone).

(3) Reef limestone extending to 65-75 feet, mainly sandy and poorly consolidated but in part compact and well cemented, showing reef corals in positions of growth. Occurrences of hard limestone at depths of 35 to 65 feet suggest that the shallow terraces at about 10 fathoms (60 feet) fringing the existing reef and lagoon may be continued beneath the island. The harder limestone of this interval with many reef corals in place suggests a recent growth of the modern reef atop an older reef represented by the terraces and by the limestone of the next lower unit (zone 4).

(4) A zone of porous, poorly cemented, white to cream-colored coralliferous limestone with algae and other fossils, extending to about 425 feet. In this interval, particularly from 300 feet to the bottom of the zone (and downward at least to 575 feet), many of the corals and mollusks are preserved as molds, suggesting that this part of the section was above sea level for an appreciable time after deposition.

(5) A zone between 425 and 725 feet wherein the material grades from a white, poorly consolidated limestone to a tan, very porous sand with a variety of fragmentary fossils.

(6) A zone between 745 and 1,100 feet in which the material is sandy and poorly consolidated but shows layers containing well-preserved shallow-water foraminifera, corals, and mollusks.

(7) A zone of fairly firm limestone from 1,100 to 1,135 feet.

(8) A section of medium to fine tan calcareous sand with a few identifiable fossils, extending from about 1,135 to 2,556 feet.

Very little magnesium carbonate is present in the samples analyzed to date. One sample from a beach sandstone core contains 8·27 per cent magnesium carbonate, but 11 other samples at intervals down to 2,500 feet contain only 0·24-3·46 per cent.

Age.—Fossils are abundant in many of the cores and cuttings. The foraminifera are now being studied by W. S. Cole; corals, by J. W. Wells; mollusks, by H. S. Ladd; and algae, by J. H. Johnson. The top of the Tertiary section has not yet been determined. Tertiary fossils have been identified from a depth of 935 feet, but the contact may lie above 725 feet and possibly as high as the 425-foot level.

Well-preserved upper Tertiary reef corals and mollusks are present in 2½ feet of sandy core recovered from a depth of 925 to 935½ feet. Many differ from species now living in the Marshall Islands, some of them being new and others identical with forms occurring in the Miocene and Pliocene of the East Indies. Among the corals is the genus *Dictyaraea*, known in the East Indies only from the Miocene and sparingly in the Pliocene. A number of the mollusk shells show original luster and traces of color pattern. Foraminifera and echinoid fragments from this interval are not diagnostic of age. Although many of the fossils show evidence of wear, it appears unlikely that they were transported appreciable distances, either horizontally or vertically. The entire assemblage indicates a depth considerably shallower than where it is now found, probably not deeper than the lower limit of vigorous hermatypic coral growth—300 feet (93 meters), and an environment of an open lagoon, shelf, or platform rather than the steep seaward slope of an island reef.

Diagnostic genera of foraminifera indicating a Tertiary age have been identified from levels below 1,020 feet (308 meters). *Operculina* is scattered to 1,020 feet, at which depth *Miogypsina* first appears, with abundant specimens at 1,303½ to 1,314 feet. *Lepidocyclina* (*Nephrilepidina*) of the group of *L. verrucosa* Scheffen occurs at this same depth. *Spiroclypeus* was found at 1,786½ to 1,797 feet, and *Heterostegina sp.* cf. *H. borneensis* van der Vlerk and *Lepidocyclina* (*Eulepidina*) of the group of *L. formosensis* Schlumberger occur at 1,986 to 1,996½ feet. Between the depths of 1,303 and 1,996 feet

these foraminifera indicate an horizon well down in the Miocene, probably lower Aquitanian, and to be correlated with Tertiary *e* of the East Indies. Calcareous algae from below 1,200 feet differ from those at higher levels and contain species that are common in the Miocene.

Geophysical observations.—Seismic investigations made in 1946 indicated that Bikini Atoll is underlain at depths of 7,000 to 13,000 feet (2,133.6 to 3,962.4 meters) by hard material, presumably igneous rock having a seismic velocity of 17,000 feet/second (Dobrin and others, 1946). This basement surface is irregular. After the drilling of the deep hole in 1947, the Geotechnical Corporation made seismic velocity tests to obtain reliable data for interpretation of the earlier records. A total of 72 seismic vertical velocity measurements were made at intervals between 1,820 and 50 feet. A preliminary review of these data shows a break at a depth of about 800 feet. Above this level there are numerous intercalated bands with high velocities. The break at 800 feet correlates reasonably well with the geological data already presented. Below 800 feet the velocity increases relatively steadily with depth to a maximum of approximately 11,000 feet/second. It would appear, therefore, that the entire section above the basement—a section one to two miles in thickness—is sedimentary in nature, probably composed of calcareous sediments not unlike those found in the lower part of the deep hole. This would indicate a total subsidence throughout the atoll's history of at least 7,000 and possibly 12,000 or 13,000 feet.

On August 16th, 1947, an airborne magnetometer survey of Bikini was made by the U.S. Geological Survey and the Naval Ordnance Laboratory. A preliminary map of the total field intensity has been compiled, but analyses of the data are not yet available.

COMPARISON WITH OTHER DRILL HOLES

Funafuti Atoll, Ellice Islands.—In 1896 the Royal Society and the Government of New South Wales sponsored an expedition to Funafuti Island under the leadership of Professor W. J. Sollas for the purpose of boring a deep hole primarily to test the Darwinian hypothesis of atoll origin. Due to

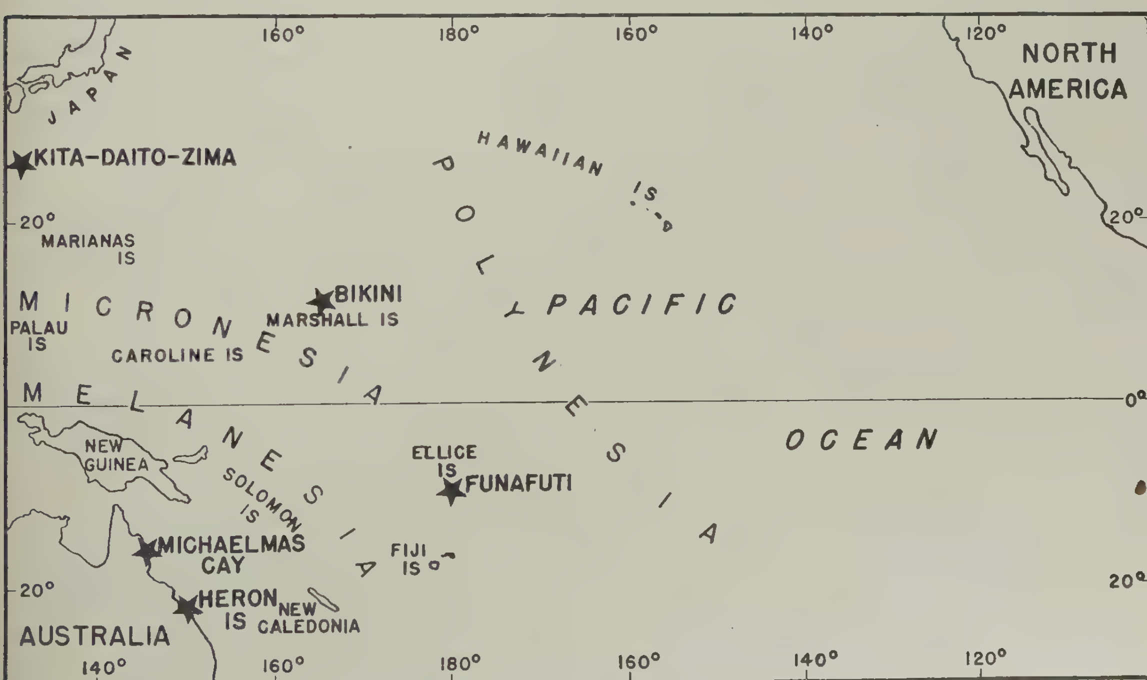

FIG. 2.

unexpected difficulties the first hole had to be abandoned at a depth of 105 feet. Two successive expeditions, led by Professor T. W. Edgeworth David in 1897 and 1898, finally succeeded in drilling to 1,114 feet (339 meters), from a point about 500 feet inward from the seaward reef edge (Fig. 2). The magnitude of this operation can only be appreciated by reading the accounts of the expeditions by Sollas and David (1904), and by noting the difficulties encountered in the Bikini boring a half century later, where the most modern equipment available was used. We must admire the courage and initiative of the men who carried out the Funafuti boring.

In the Funafuti hole, the site of which was comparable in most respects to that on Bikini, the section was quite different. From 0 to 637 feet was porous friable limestone containing corals, calcareous algae, mollusks, and foraminifera. From 637 to 748 feet was a white, soft, and earthy dolomitic limestone with fewer fossils. From 748 to 1,114 feet the rock was a hard and compact dolomitic limestone, 85 per cent of which was recovered as a solid rock core. No fossils other than recent species were reported, and shallow-water forms only were found.

Magnesium carbonate was generally 1 to 5 per cent to a depth of 637 feet, with the exception of a maximum of 16 per cent between 15 and 25 feet. Below 637 feet, in the white earthy limestone, the magnesium carbonate rose rapidly to a maximum of 40 per cent, this being maintained to the bottom of the hole with the exception of two intervals, 819 to 875 feet and 1,050 to 1,097 feet, where dolomitization was less. The lower third of the Funafuti boring thus differs radically from that of Bikini in age, induration, and chemical composition.

Kita-Daito-Zima.—In 1934-36 the Japanese cored a hole to a depth of 431·67 meters (1,416 feet) on Kita-Daito-Zima (North Borodino), a small island lying south of Japan and east of Okinawa (Fig. 2). Study of the cores by Hanzawa (1940) showed that down to a depth of 103·4 meters (340 feet) there was cavernous, indurated, dolomitic limestone, containing reef-building corals, calcareous algae, and foraminifera; from 103·49 to 116·41 meters (340 to 382 feet), grayish-blue calcareous mud with some limestone; from 116·41 to 209·26 meters (382 to 687 feet), white granular limestone; from 209·26 to 394·98 meters (687 to 1,296 feet), coarse-grained calcareous sand; and from 394·98 meters (1,296 feet) to the bottom of the hole at 431·67 meters (1,416 feet), fine-grained calcareous sand. On the basis of the foraminifera, Hanzawa refers the material above 103·49 meters to the " Plio-Pleistocene," the interval 103·49 to 394·98 meters to the Aquitanian (lower Miocene), and the lowest zone (below 394·98 meters) to the Chattian (upper Oligocene). Dolomitization was high in the upper levels, ranging from 78·87 to 90·45 per cent dolomite for the interval 0 to 103·49 meters. Below this the dolomite content dropped abruptly to 1·07 to 6 per cent, with a few intervals having a much higher percentage (41·31 to 87·56 per cent.)

The dolomitic limestones of the upper part of the section in the Kita-Daito-Zima hole have no counterpart in Bikini, but the section below 209·26 meters is much like that of Bikini, both sections being unconsolidated, non-magnesian, foraminiferal sands.

Borneo Shelf.—Kuenen (1947) has reported briefly on two holes recently drilled on Maratoea, described as a horseshoe-shaped elevated atoll, 30 by 7 to 8 kilometers, lying north-east of Borneo near the seaward edge of the shelf that extends from Borneo to the Celebes Sea. The highest point on the island is 110 meters; the lagoon is 5 to 10 meters deep. The drilling was on an islet 2 to 2½ kilometers inside the outer margin of Maratoea and presumably close to sea level. The first hole was drilled to 261 meters (856 feet), the second to 429 meters (1,407 feet). Coral limestone alternating with a mixture of pieces of coral limestone and coral sand was found to 189 meters (620 feet); from that level to 261 meters (856 feet) there was no hard limestone but mainly cemented reef detritus and soft, marly limestone merging into an olive-green limy marl. Below 260 meters (853 feet) was an irregular alternation of coral limestone detritus and soft, amorphous, non-fossiliferous limestone. No evidence is given of the magnesium carbonate content, but preliminary studies of some of the finer samples show a lime content of 83 to 98 per cent. The age of the sediments penetrated is not stated. The section, except for the greenish marl found in the first hole, is not unlike that found on Bikini.

Great Barrier Reef.—In connection with the comprehensive studies of the Great Barrier Reef of Australia, two holes were put down, one on Michaelmas Cay, the other on Heron Island (Richards and Hill, 1942). These sites are 700 miles apart, Michaelmas Cay being at about the central point of the length of the reef and Heron Island at the southern end (Fig. 2). The Michaelmas Cay hole, lying 14 miles from the seaward margin of the barrier, was carried to a depth of 600 feet (183 meters); the Heron Island hole, 10 miles from the reef edge, was drilled to 732 feet (223 meters). In each hole the material encountered for practically the entire depth was loosely coherent, and none of it was dolomitized. The northern hole passed through 378 feet (115 meters) of coralliferous limestone into quartz-foraminiferal sand; in the southern hole the calcareous material extended to 506 feet before entering the sand. Neither hole reached the basement rock. It was concluded that the limestone section was accumulated at depths never greater than 25 or 30 fathoms. Mollusks were found in the Heron Island hole to depths of 696 feet, all apparently being littoral species. Some of the foraminiferal assemblages, however, both in the calcareous section and in the sands below, consisted of worn and broken larger, shallow-water species mixed with well-preserved, smaller, deeper-water species. No extinct species were found, and it was concluded that the entire section is Recent in age.

The limestone section is similar in many ways to that of Bikini, but detailed comparison has not yet been made.

CONCLUSION

The establishment of a thick Tertiary section beneath Bikini is very significant in connection with the geologic history of the Pacific Basin,* but of even greater interest are the indications that the sedimentary section continues downward for many thousands of feet. The determination of the geological time-span of this unknown section and the environments of deposition which it records should reveal much about the evolution of the Pacific Ocean.

The character of the unknown basement rock is also a matter of prime importance. It may be a basaltic mound, but this is not certain. Other possibilities involving the fundamental structure of the Pacific should be considered. In this connection it should be noted that the atolls of the Marshall Islands, including Bikini, are aligned in two arc-like series. In this area also there are numerous flat-topped seamounts which rise to levels 700 to 900 fathoms below the surface. One of these structures adjoins Bikini as a terrace-like feature extending north-westward for 20 miles (Emery, 1946).

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DISCUSSION

R. W. Wheeler asked J. W. Wells how the depth by seismic methods was ascertained when neither depth nor velocity data were available below the deepest 2,500 ft. test on the island. He also asked: which seismic technique was used, reflection or refraction.

J. W. Wells replied to the first question that preliminary tests with hydrophones had been made; to the second that refraction had been used.

*The discovery of such a section was not entirely unexpected, as Yabe and Aoki (*Jap. J. Geol. Geogr.*, 1922, 1, 40-44, pl. 4) had previously found pellets of limestone containing *Lepidocyclina* in a Recent reef conglomerate on Jaluit, an atoll lying south-east of Bikini in the Marshall Group.

TURBIDITY CURRENTS OF HIGH DENSITY

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ABSTRACT

Laboratory experiments were carried out on turbidity currents with densities up to 2. Sand or sand, clay, and gravel were churned up and suddenly released at the head of a model submarine canyon. Velocities approaching 1 metre per second were obtained when using 20 litres of suspension on a slope of $8\frac{1}{2}°$.

Theoretically the competency to move debris by traction should be enormous. This was confirmed by experiments. Under optimal conditions the maximum weight of blocks that can be moved should be many hundreds to several thousand times greater than with clear water of equal velocity.

High density mud-flows are met with on dry land; their occurrence under water is not improbable. They might develop from slumps or from low density flows originating from wave turbulence. If formed in submarine canyons, the velocity should attain many metres per second and they should be competent to roll separate blocks of a hundred tons. Sweeping out of canyons or even powerful erosion in poorly consolidated or well-jointed rock by such turbidity flows appears a legitimate working hypothesis.

It would be worthwhile attempting to cause such flows artificially for instance by explosions in the mud or by the release of large volumes of suspension, and to study their action in a submarine canyon.

INTRODUCTION

DALY (1936) attempted to explain the formation of submarine canyons by turbidity currents. During the lowered sea levels of the Pleistocene, large volumes of mud must have been churned up on the shallowing continental shelves. The excess density of the turbid water caused it to flow down the continental slope and to cut out canyons reaching from the shelf to the deep-sea floor. The present author carried out tank experiments which tended to show that the formula used for calculating the velocity of rivers applies to these turbidity currents also. Extrapolating from the tank experiments, and from turbidity flows observed in reservoir lakes, the velocity in submarine canyons was estimated at 2 m. per second or even more under favourable circumstances. In a recent paper the suggestion was offered that, besides clay and silt, sand may likewise have been churned up, thus adding to the density of these flows. In the following paper the results of further experiments on dense currents will be reported, followed by a short discussion of the application to natural conditions.

I. EXPERIMENTS*

The present experiments were carried out in an aquarium of 2 metres length and 50 cm. depth and breadth with a lid. It could be tilted lengthwise to high angles. The heavy suspension was churned up in a bucket, hung in the aquarium at the higher end. The bottom of this bucket could be turned aside so as to release the flow into the aquarium. A depression was modelled in sand, covered with a layer of gypsum, to guide the current along the front of the aquarium.

On release, the dark, opaque suspension drops out of the bucket and rushes down along the model canyon with surprising rapidity in a highly turbulent tongue of liquid. The maximum velocity attainable is nearly 1 m. per second. The flow bounds up against the lower end of the tank and is partly reflected, partly directed round two sharp turns and back up the opposite side.

*Expenses were defrayed by a grant from the "Netherlands Foundation for Pure Scientific Research" (Ned. Organisatie Z.W.O.).

The main factors determining the velocity of a turbidity current are: size, density, slope, viscosity, and turbulence. Our main problem is whether the velocity in a submarine canyon can be deduced if reasonable values for these factors are assumed.

The formula for calculating the velocity of a river is:

$$V = C \quad \sqrt{m \times s \times d}$$

in which V is the velocity, m is the hydraulic mean depth (area of the cross-section divided by the wetted perimeter), s is the slope, and d is the density. The constant C is determined by viscosity and turbidity. In rivers it generally amounts to 700 in c.g.s.-units.

It would lead us too far into technical matters to give a detailed treatment of the checking of this formula and the calculation of C for our type of current. By varying the slope, density and volume each in turn and measuring the velocity, it was ascertained that the formula applies reasonably well. The slope, however, must be replaced by its sine, because larger angles are used than those which occur in rivers.

In a former paper, C for low-density turbidity currents was estimated at 400. In the present flows the suspended sediment must cause greater viscosity and therefore lower values for C. It was found to vary somewhat, averaging, very roughly, 120, a value that appears reasonable.

II. MAXIMUM DENSITIES

When more and more clay is added to water the suspension gradually thickens until finally a plastic solid is formed. No sharp boundary is found between a viscous liquid and a plastic solid. This boundary

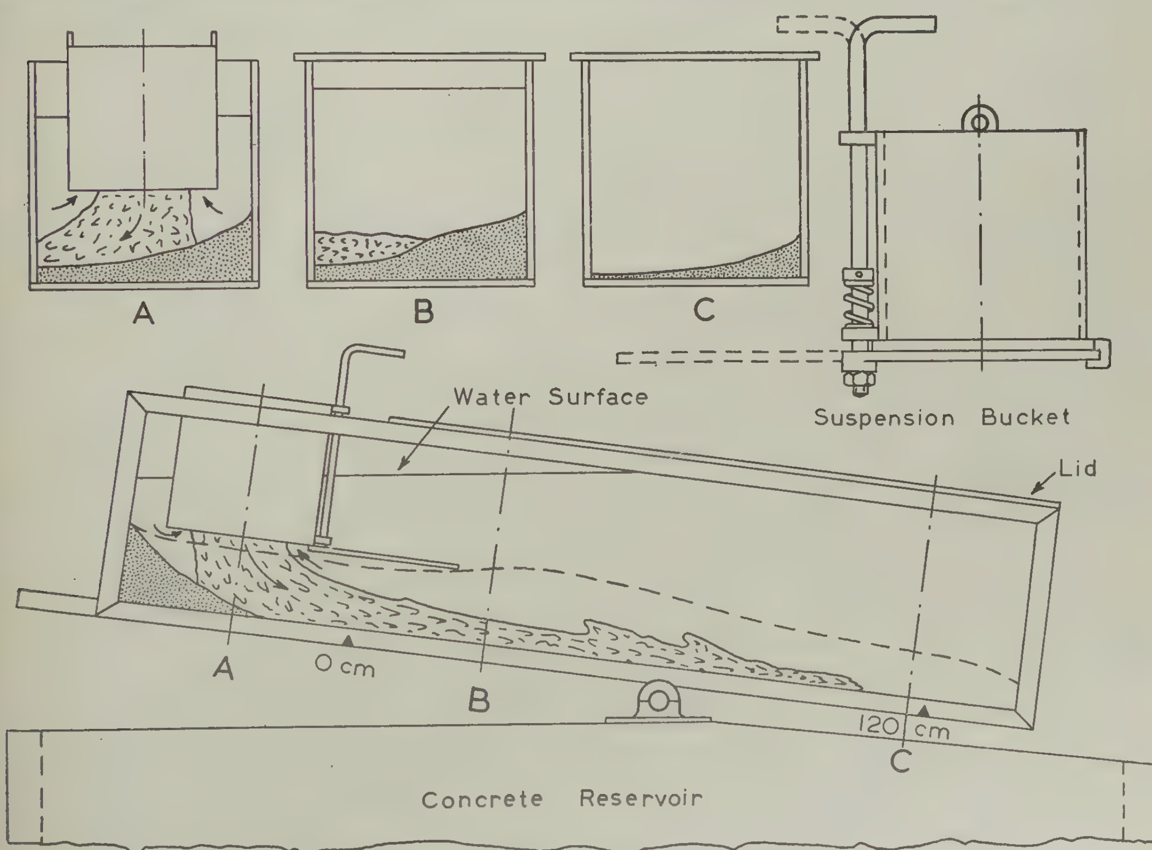

FIG. 1.—*The tilted tank and three sections, with a turbidity flow.*
Top right hand, the suspension bucket at twice the scale.

is rendered even more vague because the larger the mass of suspension the more it will tend to show liquid properties such as turbulent flow. Nevertheless the transition from one state to the other is fairly swift. Using a medium pottery clay it was observed that the transition takes place roughly between mixtures of 1 water with 1·5 clay and 1 water with 1·7 clay by weight (specific gravities of mixtures 1·55 and 1·59). But while the former mixture reacts definitely like a liquid when stirred in a bucket with a stick, it behaves more as a solid when released down a subaquatic slope. The flow is found to attain a considerable velocity, but the surface is hardly turbulent.

The thicker mixture shows the same velocity, but no turbulence at all, the larger motive force being compensated by the greater internal and bottom friction. When the water in the tank is drawn off, a tongue of mud remains on the floor of the model canyon crowded with cracks, strongly reminiscent of a glacier surface.

When the amount of clay in the suspension is only slightly decreased so that a composition of 1 water with 1·3 clay is used, a normal turbulent current results.

If pure sand is churned up with water there is found to be a more marked boundary between a suspension and a solid mass. With the fine sand used in these experiments it occurred between the mixtures: 1 water with 3·6 sand and 1 water with 4 sand by weight (specific gravities 1·95 and 1·99), the latter being so stiff that it can hardly be stirred. When the lighter suspension was used almost all

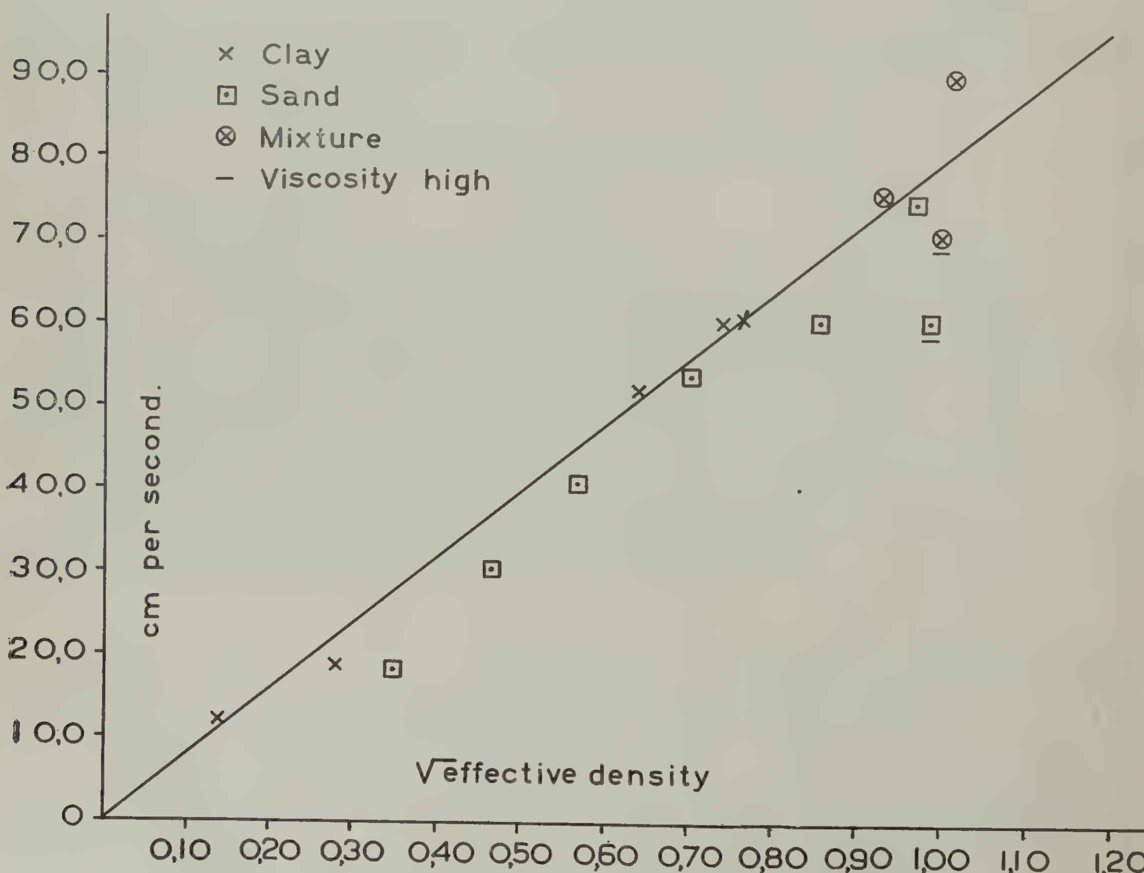

FIG. 2.—*Measured velocities of the head of various turbidity flows against the root of their densities, showing straight line relation passing through the origin.*
Slope of canyon $8\frac{1}{2}°$, volume about 12 litres.

sand was carried down the canyon, while with the heavier suspension it was nearly all deposited within the first metre.

Mixtures of clay and sand show peculiar properties. Over a fairly wide range of clay suspensions a great amount of sand can be added without causing much thickening of the liquid. Yet the clay prevents the sand from settling.*

When, however, the amount of clay is less than about one third of the water it is no longer able to prevent the sand from settling. In a few seconds after being stirred up practically all the sand has settled out and the clay accumulates gradually on top with a sharp margin.

Although the combined suspension differs from a pure sand suspension in that practically no settling occurs, the specific gravity shows roughly the same maximum, namely slightly less than 2. In a turbidity flow we may expect the addition of clay besides sand not to increase the velocity but to keep the sand from settling and thus to lengthen the distance over which transport takes place.

Finally gravel can be added to the combined suspension and if the latter is fairly thick the larger particles will show little tendency to settle. A slight amount of turbulence should suffice to keep the gravel in suspension as long as the movement continues. This combination of a wide range of grain sizes allowed the highest densities to be given to the suspension while it still remained a liquid. With the materials used in the ratio of water: gravel: sand: clay = 5: 12: 8: 3 by weight a specific gravity of 2.03 was obtained.

While in motion, with larger fragments held in suspension by turbulence, a slightly higher density is theoretically possible. But it requires a rather delicate balance between the amounts of the various grain sizes involved. Hence, in nature a specific gravity of 2 may be taken as the limit attained under the most favourable conditions.

III. COMPETENCY TO TRANSPORT DEBRIS

In treating the transport of debris by clear running water, a distinction should be made between transport in suspension, by saltation and by traction along the bottom. For each of these actions the load actually moved, and the maximum that could theoretically be carried, should be distinguished. Also the maximum size available and the maximum that could theoretically be handled should be considered.

In the present experiments the length of the flows was limited by the comparatively small size of the tank. Moreover, when the current reached the bottom end it was reflected and on the return up the canyon a lot of sediment was added to that already deposited during the first passage. Hence no accurate measurements could be made of the amount deposited by the flows on their way down the model canyon. By draining off the water and measuring the amount of sediment in 4 equal areas of the canyon after each experiment the general trends could be established, however. It was found that with increasing velocity, whether due either to higher slope, greater volume or greater density, a larger proportion of the original load was transported to the lower end of the canyon.

When a layer of sand was present on the canyon floor before a flow passed, it could be observed that first a small amount of erosion occurred but that a larger amount was deposited in later stages. When the main mass of the suspension had passed, a slower and more diluted current, formed from the last remains of suspension dropping from the bucket, continued to flow for some time after. This sluggish tail was the main cause of deposition, especially with swifter currents, which drop very little sand themselves.

The above observations of lessening deposition with increasing velocity, and of erosion by the swift forward portions of the faster flows, would appear to indicate that with higher velocities than attainable in the experiments, erosion must become important. This would mean that the total

*The curious phenomena leading to a partial separation of clay and sand when the mixture is left to settle, will be treated in a separate paper.

sedimentary load gradually increased and that either the volume or the density of the flow would become larger. In either case the velocity and erosional force would be maintained or even augmented *en route*.

More definite conclusions can be arrived at concerning the maximum size of separate boulders that can be rolled along by the density flows. It is easy to show that the competency of a turbidity current to transport debris must be larger than of a clear flow of equal velocity. Owing to the higher specific gravity the impact of the current against a stationary object is increased, while the " underwater weight " of this obstacle is reduced. With augmenting density of the flow these factors first remain relatively unimportant, but beyond density values of $1\frac{1}{2}$ remarkable competency begins to develop. Finally with the greatest densities of about 2 the following fantastic figures are obtained.

The impact is doubled, which means that the maximum weight of pebbles that can be rolled along should be multiplied by 2^3. The effective specific gravity of a block with an actual s.g. of 2·5 is reduced from 1·5 in clear water to 0·5 in our suspension. This in turn should raise the maximum size by a factor 3^3. Together these two influences raise the maximum size in volume or weight by 216. This brings into play yet another factor. The size of pebbles or cobbles which can be rolled by rivers is determined by the velocity of the current very close to the bottom, the so-called bottom velocity. But in a dense turbidity flow—the diameter being 6 times as large—the boulders will be affected by the main body of the current. It is generally held that the bottom velocity is half that of the remainder of the flow. This means that with a dense turbidity flow the velocity determining the tractional force is double that of a clear current. From the law on the relation between velocity and size of debris transportable it follows that another factor of 2^6 should be added in the case of our dense flow. This brings the total up to a factor of no less than 13,824 for volume or weight and of 24 for diameter.

This theoretical deduction requires experimental confirmation. Traction by pure water has been studied in nature and laboratories by measuring the velocity at which a more or less complete covering of the bed is set in motion. In the present series of experiments this procedure cannot be followed, because, as set out above, the flow lasts too short a time for trustworthy observations of bed erosion. Hence a different method of study was chosen.

A few separate pebbles of different sizes were placed in the canyon and the velocity was noted of a flow which was capable of rolling some of them along. In this manner it was ascertained that a flow of 50 cm. per second was able to carry away a rather angular quartz-porphyry pebble weighing 1 kilogram.

A current of twice this velocity should be able to roll along a boulder of 64 kilograms. But a block of that weight is much too large to be submerged in the experimental flows. In order to gain an impression of the traction exerted by a swift but shallow current an angular wooden pebble of 270 cm^3 was constructed weighted by lead. The weight was first chosen too high for movement by a current of 89 cm. per second. When the specific gravity was reduced from the original 4·04 to 3·67 the current rolled the pebble right away down the canyon. It may be assumed that 3·75 is the limit. Simple calculation shows that a current of equal density and velocity and of sufficient depth to submerge a large block should be able to roll along a sandstone boulder with specific gravity of 2·5 weighing 29 kilograms.

The competency of the turbidity flows to move debris by traction thus established cannot be directly compared to the available data for clear water, because the latter appertain to uniform bed covering. Hence a series of measurements had to be made with clear water acting on single grains. A slightly modified version of Nevin's traction tube was used. The tube was coated on the inner wall, one side only, with coarse sand, using Canada balsam. Single quartz or lydite pebbles of various sizes and shapes were tested. The greater the sphericity (or approach to a rotational ellipsoid around the longer axis) the smaller velocity is measured for a given weight of pebble.

The competency, as understood in this sense, is surprisingly large compared to that relating to a complete bed covering. The diameter of a separate particle which can be rolled on a rough bottom is roughly 13 times (the volume 2,000 times) as large as that of the grains in a uniform bed that is set in motion by the same current of 25 cm. per second. This is due mainly to the much greater

exposure of a single pebble to the impact of the current than of a grain protected by directly adjoining neighbours. The turbulence around a separate pebble is probably also greater and hence the tractional force larger. The velocity is almost equal throughout the entire cross-section of the traction tube. Hence the velocity measured is the bed velocity; the corresponding current velocity should be taken as double this amount. The bottom slope plays no appreciable part below 10°.

We are now in a position to compare the measured competency of density flows to that of clear currents. At a bed velocity of 25 cm. per second, corresponding to a current velocity of 50 cm. per second, clear water can just roll a grain weighing 0·16 grams. A density current of 50 cm. per second was found capable of rolling a pebble weighing 1 kg. The factor thus established amounts to 6,250. Although this is only half of the amount calculated, one could hardly expect closer correspondence. Certainly the experiments amply confirm the remarkable competency of turbidity flows deduced theoretically.

Extrapolating from the measured values for competency of the turbidity flows of density 2, we find that: at 1 m. per second the density current should be able to roll boulders weighing 50 kg., at 2 m. per second 3·2 tons, at 4 m. per second 205 tons.

These figures, it should be recalled, all apply to currents of maximum density. With falling density the competency quickly sinks. At a density of 1·5 the transporting power has been reduced from the theoretical factor of 13,000 (at density 2) to one of about 100.

IV. TURBIDITY CURRENTS OF HIGH DENSITY IN NATURE

Mud-flows are known to occur on land. They are particularly frequent on certain Javanese volcanoes where they are known as "lahars." These are produced either by tropical downpours or by the ejection of a crater lake. The fine volcanic ash and clay become mixed with water in such a ratio that a thick pasty liquid is formed. Lahars generally flow down the slopes at great velocities and are known to transport huge boulders. These have been found suspended between the branches of trees at the edge of the flows, when the lahar had passed. This shows that while the velocity was already insufficient to uproot the tree, the buoyancy was yet so great as to lift the boulders many feet above the ground.

Probably all transitions may occur on land between these comparatively swift mud-flows and, on the one hand, "mud glaciers" creeping along imperceptibly, and, on the other hand, muddy streams.

Numerous instances are known of structures in sediments due to subaqueous slumping. In these cases a slow or possibly swift sliding of a mobile, plastic solid must have occurred. Much contorted remains of the original lamination are found and these form the principal evidence of the movement. There can have been no true turbulent flow because in that case all remains of the original structure would have been destroyed. A turbidity current, to deserve that name, must show complete mixing and renewed deposition of the transported material. Some sorting at least should also result after coming to rest. The deposit of such a flow is probably inconspicuous in a sedimentary series. The sole might show current ripple marking, huge boulders might be enclosed or left stranded, gullying might have preceded deposition. Perhaps field geologists will eventually discover such evidence of deposition from turbidity flows if they keep the possibility in mind.

Daly (1936) has pointed to the occurrence of turbidity flows in Swiss lakes and reservoir lakes. These are all of low density. Whether flows of higher density also occur is less certain. The only occurrence of a turbidity flow of larger proportions in nature known to the writer is indicated by A. Heim in connection with slumping in Swiss lakes. He has described the sudden appearance of boiling masses of muddy water on the side of the Zurich Lake opposite to where the shore had disappeared in a large slump.

Obviously the slump itself could not rise much beyond the deepest part of the lake. In fact soundings showed that the main mass had spread out in a thin stratum on the deeper floor of the lake.

Besides the paste-like slump a separate watery turbidity current must have developed. In order to reach the surface again this mass of water must first have obtained a considerable momentum on the down slope owing to high turbidity. This momentum then carried it up the opposite slope to the surface.

On a small scale turbidity currents are in continuous action as accompaniment of the churning up of sediment by wave action especially that of surf. The distance of transport will in general be small and the action will frequently be masked by superimposed currents due to waves, tides, etc. However, the aggregate amount of transport caused in this manner, especially on steep shores, must render these short-lived turbidity flows a major geological factor. This aspect of sedimentation deserves separate treatment.

The point the writer would specially like to stress is the possibility of turbidity flows with high to maximum density occurring in submarine canyons. On the one hand turbidity currents of low density caused by wave action, as invoked by Daly (1936) and the author, might surpass a critical velocity at which the churning up of sediment equals loss through settling and diluting. The density of the flow would then gradually increase until the maximum is reached. Further increase is then excluded because of rising internal friction and consequent lessening velocity of the thickening liquid. The lifting of sediment is activated by strong vertical turbulence because the surface is billowy, a feature lacking in rivers. The alternation of flow and stagnant water should also favour turbidity.

On the other hand, where a canyon has become sufficiently incised, or where tectonic action has caused the development of a submarine scarp, a slump of unconsolidated sediment may occur.

Shepard first suggested that slumping may have played a part in cleaning out buried submarine channels on the continental slope. Several authors have later invoked slumping as a factor in the development of the canyons. More recently Shepard (1941) found very strong evidence in favour of slumps in canyons off California. It is here suggested that the mechanism may sometimes involve the development of turbidity currents. Once started down the slope there would appear to be a reasonable chance of the slump becoming watered down to a turbid liquid. In fact this is what has occurred in the case of Zurich Lake, cited above. The further the slump can continue the higher the chances of this metamorphosis occurring in part of its mass.

For two reasons the latter mode of origin cannot account for the initial development of the canyons. Firstly it cannot act until a steep walled cut has already been formed by other processes. Secondly the Pleistocene age of the canyons requires explanation. While turbidity currents due to the churning action of storm waves must have been enormously stimulated by glacial lowering of sea level, there is no apparent reason why slumping should have been active only during the Ice Age but neither before nor since.

On the other hand, once the cutting of the canyon has been started, slumping should form one of the major processes in operation. In a former paper (1947) the writer deduced that the major part of the canyon content has been removed in the first instance by sliding down the walls to the canyon floor. The transformation of these submarine landslides to currents of high turbidity and their scouring effect further out towards the deep-sea floor is no unreasonable postulate.

The author would like to submit for careful consideration the following working hypothesis for the formation of submarine canyons.

The canyons were first cut by turbidity currents developed in consequence of wave action. Silt was the main agent, but sand was of importance, especially after the canyon heads had been cut back close to the glacial shore line. Running down the slope they tended to become more dense by the addition of fine and coarse sediment. As soon as steep walls began to develop these were continually attacked by rock slides and slumping. The slumps frequently formed high density flows. These were particularly important, because they swept away the coarse debris left along the canyon floors by currents of lower density, and by slides that did not turn to currents. They continued to occur as long as active down-cutting of the canyon floor undermined the walls. During high sea levels (interglacial, present) slumps

were apt to occur occasionally after much sediment had accumulated on the slopes, especially during earthquakes.

Canyons that have been cut back close to the present beach continue to receive a surfeit of sediment washed in by longshore currents. The new deposits are apt to slump away from the canyon head and to form high density flows. Low density flows are also still generated by wave action around the head of these canyons.

Assuming the development of high density currents, the question arises as to how great the velocity can have been. In the experiments the maximum density acting along a canyon sloping at $8\frac{1}{2}°$ resulted in a velocity of $0 \cdot 9$ m. per second. The depth of these currents was 10 cm. On a slope of 3°, a normal value for a canyon, a current 30 cm. deep should attain the same velocity.

The following table indicates roughly the velocities and maximum weights of angular boulders which can be transported, when currents of various depths and densities are assumed in a canyon sloping 3°.

	density 2		*density 1.5*	
depth	*velocity*	*max. weight*	*velocity*	*max. weight*
1 m.	1.5 m/sec.	550 kg.	1 m/sec.	2.5 kg.
4 m.	3	30 tons	2	160 kg.
16 m.	6	2000 tons	4	10 tons

Although it is not possible to ascertain the dimensions of currents in nature it does not appear unreasonable to estimate the maximum weight of boulders that have been swept away by this mechanism at many tons.

Many arguments in opposition and in support of canyon cutting by turbidity currents have been brought forward. There is no opportunity here of reviewing these. But even if the cutting power of density currents is considered doubtful, they might still be held as important agents in cleaning out existing furrows and in distributing sediment on the sea floor, as Stetson and Smith (1938) first suggested. They might possibly explain the observed occurrence of sand layers encountered here and there in deep-sea deposits far from the shore.

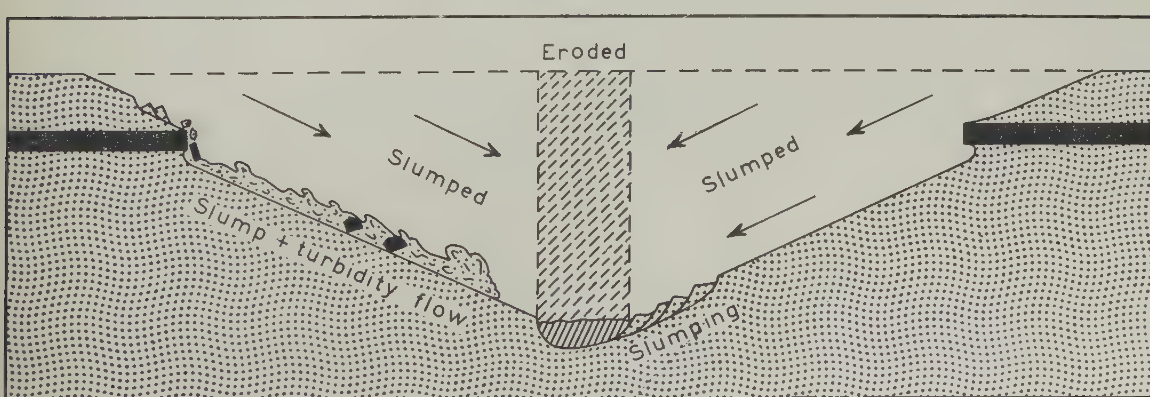

FIG. 3.—*Schematic transverse section of submarine canyon showing small amount directly eroded and large amount removed by slumping.*

Many occurrences of graded bedding may be due to deposition from turbidity currents of high density when these have spread out and come to rest on basin floors, each bed resulting from a separate flow.

In conclusion I might suggest that high density currents could be caused artificially in a submarine canyon, either by explosion or the release of a large volume of suspension. The velocity, dimensions, and constitution could then be ascertained by suitable means.

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DISCUSSION

R. D. RUSSELL asked the author whether he intended to imply that density currents may actually cut submarine canyons, or only keep them open by transportation of material which would otherwise accumulate in them. If the former, how could he explain vertical canyon walls cut in rock?

PH. H. KUENEN replied that unless the hard rock had previously been shattered by faulting the turbidity currents would not be adequate to erode canyons, but that the problem was too extensive to consider then.

J. J. BOURCART referred to Kuenen's experiments but doubted whether his theory would account either for the morphology or stratigraphy of the Mediterranean submarine canyons as off the mouth of the Rhône.

C. I. MIGLIORINI argued that when a high density current ceased to move larger blocks, the finer material would pass down gentle slopes to the lowest enclosed depression and there give rise to well graded sediments. This had been postulated by Migliorini (" Sul modo di formazione dei complessi tipo macigno," *Boll. Soc. Geol. Ital.*, 62, p. 48, Roma 1944) as an explanation of synorogenic deposits in such mountain belts as the Apennines, Carpathians, Aegean Islands and Cyprus.

The gradual off-shore decrease in sedimentation would bring about progressive steepening of the sea floor, especially neighbouring a nascent mountain. In these circumstances at a critical angle of rest the trigger action might be further sedimentation, earth movement or marine storm to cause a submarine landslip with a resultant cloud of turbid water.

O. T. JONES welcomed Kuenen's work and agreed that, while landslides or slumps might cause both canyons and turbidity currents, the turbidity currents would keep the canyons clear.

A. LAMONT said that probably the first recognition of contemporaneous structures due to turbulent flow was by Mallet over 100 years ago in the " Calp " (muddy carboniferous limestone) of Dublin. Goodchild's work on flowage and slumping in Scottish early Carboniferous sediments was more than 50 years old.

PH. H. KUENEN later showed a film of his experimental tank with turbidity currents.

THE ORIGIN OF THE NEOCATHAYSIAN SEAS

By J. S. LEE

China

ABSTRACT

The seas under consideration comprise the Pohai, Yellow Sea, East China Sea and the Sea of Japan. These waters being distributed on the continental border where tectonic disturbance and igneous activity are equally intense are often not unnaturally supposed to have drowned a part of the "circumpacific orogenic belt." In reality, however, there exists no direct connection between these submerged and half-submerged lands and the Cordilleras or the Cordilleran geosyncline.

Tectonic analysis of the emerged parts of this region goes to show that the whole area has been repeatedly affected by strong foldings since the latter part of the Jurassic with their axes (1) running nearly east-west in certain zones, (2) describing, in certain parts of the region, a succession of similar arcs with their convex front facing south and a rectilinear, meridional zone on the concave side of the arcs—the epsilon type of structure, (3) striking north-east, the Cathaysian, (4) striking N. 30° to 34° E., the Mesocathaysian, and (5) striking N. 18° to 25° E., the Neocathaysian. These, especially the last three categories of folds and thrusts, are always associated with tension and shear faults or glides which, together with the synclinorial folding, are largely responsible for the breaking up and sinking of the lands now flooded by marine water.

WHEN we are reminded by such impressive phrases as the "Pacific ring of fire," the "circumpacific orogenic belt" and the like, it seems difficult to avoid the general notion that in the development of the circumpacific lands there has been always something inherently Pacific. Some kind of kinship between these lands, perhaps more in their foundation than in their superstructure, is probably not to be denied. It remains, however, to be shown whether we can speak tectonically of the Pacific coast as a homogeneous whole and as a specific type with the same assurance as we may do of the Atlantic.

The origin of those waters that are here collectively termed the Neocathaysian Seas, namely the Pohai, Yellow Sea, East China Sea and the Sea of Japan, is therefore a question which, apart from its intrinsic interest, has a bearing no less important on the problem of the development of the Pacific Basin than on that of the structural history of the eastern Asiatic continent. Since we are at present directly concerned with the former issue, it would seem relevant to inquire, first of all, how far the level of these seas has fluctuated in recent geological times, and how much of such fluctuations is really eustatic.

Information so far received on the subject is deplorably scanty, and the little that may be relied upon is rather varied in nature. We have, on the one hand, stretches of what appear to have been well-developed but strongly dissected marine platforms, one some 30 m. and the other less than 10 m., above the present sea-level, traceable here and there all along the South China coast, and apparently comparable with the two lower rock terraces observed in the Yangtze Valley. On the other hand, excellent examples of drowned valleys down to the depth of 540-720 m. below the present sea-level have been found on the east coast of Korea, north-east and south-east coasts of Yezo, and around Honshu or the Main Island of Japan (Yabe, 1929a). A detailed study of those developed in the southern part of Formosa has led T. Y. H. Ma (1946) to claim that during the flourishing periods of the Moji and Siobara floras, i.e. in the early and middle Pleistocene times, eastern Asia was twice elevated, between intervals of subsidence, to the extent of 1,300-1,500 m., figures which are not incomparable with the depths of the apparently truncated tops of some 160 volcanic cones reported by H. H. Hess (1946) from the Mid-Pacific. In fact an uplift of land to an extent much less than this, say 100 m. in amount, would be enough to convert the Yellow Sea and the East China Sea into an

expanse of a monotonous plain with but a narrow belt of marine water remaining on the inner side of the Riukiu arc as will be seen on the accompanying map. Such a lowering of sea-level may well have been brought about during the maxima of glaciations, as is indeed shown by the spreading of the mammalian fauna of those ages in China and Japan.

It is, however, highly questionable whether the drowned valleys referred to should indicate, of necessity, an uplifting of the Asiatic continent as a whole. A deep boring in Tientsin has, in fact, revealed a continual deposition of freshwater sediments down to the depth of nearly 2,000 feet below the present sea-level without reaching their bottom. Systematic excavations across the Tsientang Estuary, south of Shanghai, showed, on the contrary, no sign of drowning or of silting up of any formerly deepened channel in the shallow and base-levelled bottom of that strongly meandering river, as might be expected if the land was once elevated to over one thousand metres higher in recent geological time than it stands now. The probability is therefore high that the record so far found regarding the relative displacement between the land and the seas under consideration is at least partly to be attributed to the warping of the land surface. These facts throw some light on the recent changes that have happened to these Asiatic waters. They do not however afford any useful evidence as to their origin. For that part of the question we must turn to the structure of the lands surrounding them.

For our present purpose we need only consider the leading tectonic elements especially with regard to their natural association and inter-relation. In view of the first rate importance of such relations a few words on them may be excusable. A group of elements may form an independent and complete tectonic system, that is, one produced by a single process of tectonic movement, or may only form a part of a system whose various components still remain to be ascertained. Five types of syntaxial relation between different tectonic systems have been recognized. Four of them refer to folds and thrusts: (*a*) superimposition occurs when the trends of the superposed elements perfectly agree. This usually involves posthumous movements (*sensu stricto*) which, for this reason, are often overlooked, especially in regions like North China where there exists only scanty stratigraphical record. (*b*) Juxtaposition takes place when the folds or thrusts of one system, usually the younger, run across those of another, usually the older, differing in trend by a small but perceptible amount. (*c*) Transposition is brought about when elements of one system fling against, and often terminate, those of another. (*d*) Interposition is effected when elements of one system run across those of another at intervals without demolishing, but with some modification of, their original trends.

In the third type those elements which are intercepted often suffer drastic modification in trend, with the tendency to adapt themselves to those arranged across them as they approach the junction; whereas in the fourth type adaptation becomes mutual with reciprocal effect of more marked modification in trend as the leading elements of either system approach one another. Referring to superposed fault systems only (*e*) the apposition type has been found to be of some importance in the region under consideration. The younger which is invariably the larger one of the semi-concurrent, or apposite, faults, though as a whole it exhibits a definite general trend of its own, usually partially and sometimes wholly follows a zigzag course by locally taking advantage of pre-established fractures, faults or master joints, which run in directions different from the general trend of the main fault superposed on them.

It is of utmost importance to grasp these systematic and syntaxial relations between the different groups of elements in order to understand their potent influence over the apparently irregular distribution of the seas on the inner side of the island arcs. A rapid survey of these relations between the relevant tectonic elements may be facilitated by referring them to five classes and some sixteen groups essentially based on their orientation with, of course, due allowance for the geometrical necessity that the strike of a given plane or any plane parallel to it, when considerably extended, depends on the latitude and longitude of the locality and the amount by which it hades (Lake, 1931), and also for local variation in strike due to the presence of an indurated mass against pliable strata and non-uniform distortion of the features subsequent to their production.

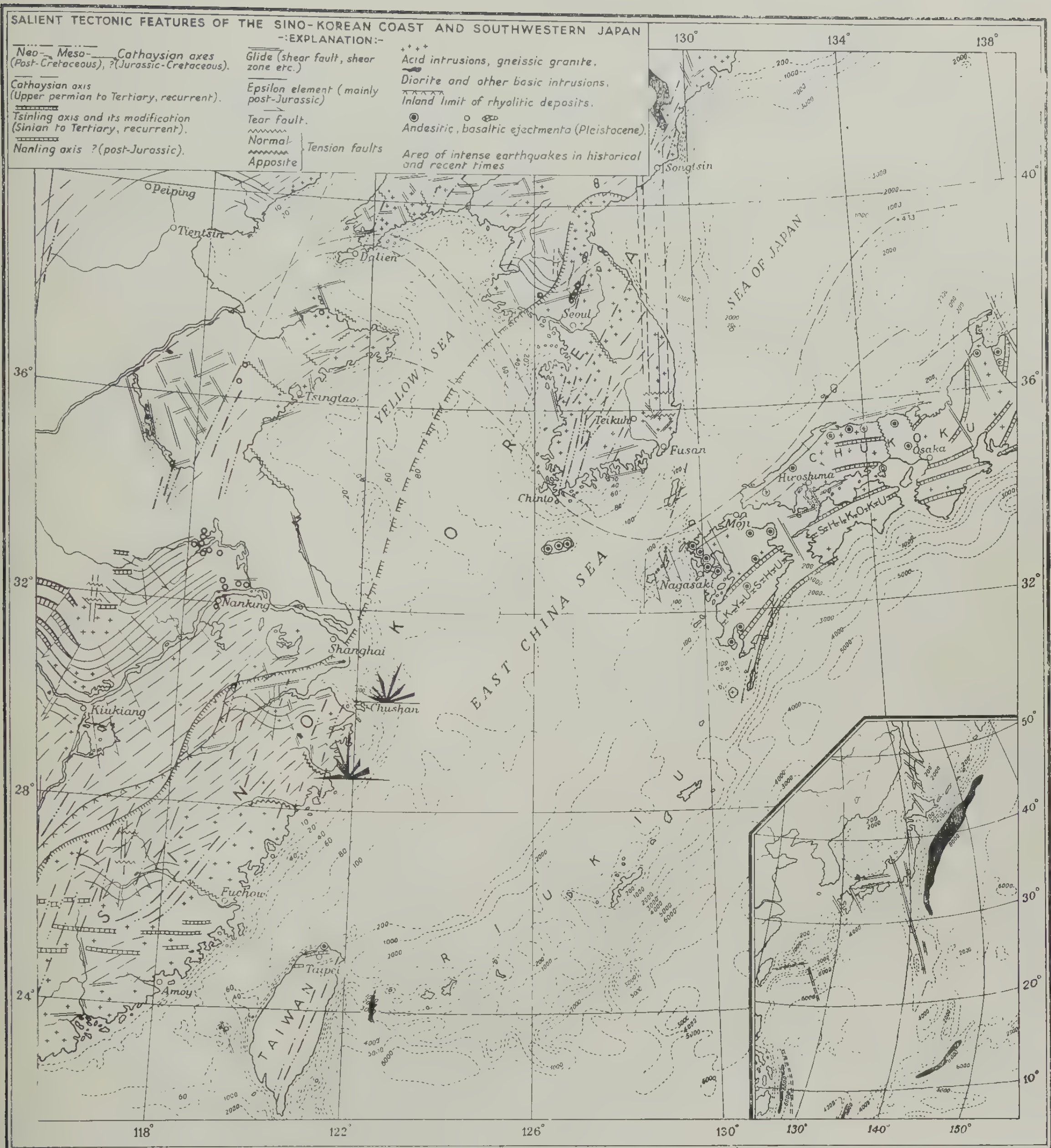
SALIENT TECTONIC FEATURES OF THE SINO-KOREAN COAST AND SOUTHWESTERN JAPAN
-:EXPLANATION:-
Neo- Meso- Cathaysian axes
(Post-Cretaceous), ?(Jurassic-Cretaceous).
Cathaysian axis
(Upper permian to Tertiary, recurrent).
Tsinling axis and its modification
(Sinian to Tertiary, recurrent).
Nanling axis ?(post-Jurassic).
Glide (shear fault, shear zone etc.)
Epsilon element (mainly post-Jurassic)
Tear fault.
Normal
Apposite
Tension faults
Acid intrusions, gneissic granite.
Diorite and other basic intrusions.
Inland limit of rhyolitic deposits.
Andesitic, basaltic ejectmenta (Pleistocene).
Area of intense earthquakes in historical and recent times
Peiping
Tientsin
Dalien
Seoul
Songtsin
Tsingtao
Teikuh
Fusan
Chinto
Nanking
Shanghai
Chushan
Kiukiang
Fuchow
Amoy
Taipei
Hiroshima
Osaka
Moji
Nagasaki
YELLOW SEA
SEA OF JAPAN
EAST CHINA SEA
TAIWAN
118°
122°
126°
130°
134°
138°
140°
150°
36°
32°
28°
24°
40°
50°
30°
20°
10°

Fig. 1.

I. SINOID FOLDS AND THEIR RELATED FAULTS

If the overworked term Sinian is still to be saved for tectonic description it will have to be modified, preferably in such a way as to suggest a wider reference to folds than only to those trending strictly north-east. Sinoid might do. Thus defined, the Sinoid folds fall into three groups each belonging to an independent tectonic system.

(1) The Cathaysian system, which consists of folds and sometimes overthrusts running N.45° to 50° E. and faults cutting across the folds nearly at right angles, attains even wider distribution in eastern Asia than was originally realized by Pumpelly and Richthofen. It involves formations of probably Triassic age in North China where Richthofen recognized the famous "gridiron structure," uppermost Permian in Manchuria and north-western Korea and metamorphic Palaeozoics in central Japan. In southern Korea and south-eastern China folds of the same trend sometimes even affect the volcanic series, red sandstone and granite intrusions of upper or post-Cretaceous age. Faults belonging to this system, especially those running south-east, seem to be largely responsible for the development of the south-western coast of the Liaotung Peninsula and the north-eastern coast of Shantung.

(2) The Mesocathaysian system with folds and often overthrusts running north-north-east or more specifically N.30° to 34° E. and faults at right angles to them forms elevated belts of land-mass and mountain ranges such as those extending from the Great Khingan between Mongolia and Manchuria to the Shuehfengshan between the Osi-Kweichow Plateau and the Central Yangtze Basin, and those comprising the Sikhota-Alin, the south-east highland of Manchuria and the Taiyun Range parallel to the south-eastern Chinese coast. In all these orogenic belts Jurassic formations, and in some cases probably Cretaceous strata, are involved in the Mesocathaysian folds. Between these raised, folded and igneous-ridden lands of Mesocathaysia stretches an elongated and somewhat sinuous trough, a para-marginal geosynclinal, from Liaoho Valley to the Central Yangtze Basin with the Pohai occupying the area of greatest subsidence and standing in relation to the Manchurian Plain in much the same way as the Persian Gulf does to Mesopotamia and the Adriatic to the Venetian Plain. When viewed as a whole this trans-continental depression assumes, however, the Neocathaysian trend, being in juxtaposition with regional Mesocathaysian axes.

(3) The Neocathaysian system with highly inclined overthrusts and sometimes overturned folds running N.18° to 25° E. and faults perpendicular to them is usually juxtaposed with antedated Cathaysians and Mesocathaysians, and forms, together with elements of these systems, a plexus as it were in the structural fabric hemmed in broad belts of plication *à sec*, which trend similarly to the Neocathaysian folds. Overthrusts sometimes directed inland and sometimes towards the sea and compressed folds belonging to this system are best developed in southern China, where they involve the Red Sandstone, and in the shattered coastal belt of the Asiatic mainland, Sinokorea—a terrain characterized by extensive exposures of granitoid gneiss, schist and other old metamorphics, a mighty sequence of volcanic deposits and congested igneous intrusions ranging from granite porphyry and aplite to porphyrite and lamprophyres with rare association of small bodies of diorite, gabbro and the ultra-basics. These are supposed to have arrived largely in pre-upper Cretaceous times, for the volcanic series associated with the intrusions and distributed in and around the Chushan Islands, north-eastern Chekiang, is cut across by faults belonging to the Neocathaysian.

The Neocathaysian system is by no means confined to these areas. A powerful zone of fracture, perhaps of the nature of a ramp of Bailey Willis (1928), extending across Shantung from Ishui in the south to Weihsien in the north, another zone separating the Lower Palaeozoics of western Liaotung Peninsula from the Archaean schist in the eastern, the compressed folds and numerous thrusts running along the north-eastern coast of Korea, the arrangement of the granite masses in Tsushima, the trend of the belt of young formations along the south-eastern coast of Kyushu, the alignment of the islands forming the northern Riukiu arc, and even the entire mass of the north-eastern part of the Main Island of Japan, all disclose traits of Neocathaysian compression. It follows therefore that in the intervening trough, the Sea of Japan and the East China Sea, we have a modern example of marginal

geosyncline. The para-marginal trough of the Pohai and its north-eastern and south-western extensions have no doubt come into being for similar tectonic reasons. The same reasons cannot however account for the existence of the Yellow Sea.

II. THE EPSILON TYPE OF STRUCTURE

Some eight different tectonic systems of the epsilon type are known to have taken part in the architecture of the eastern border of the Asiatic continent. Only with one of them are we directly concerned for the present. This may be named—(4) the Liaohan system. It is a notable fact that the distorted appearance of the Shantung Peninsula agrees with its curvilinear tectonic axis, i.e. with convex side facing north; similarly curved axes are also recognizable in the southern part of the Liaotung Peninsula, particularly clear to the south of the Adams Bay where the folds in Cambrian and Sinian beds strike east-north-east in the western part of the peninsula, but begin to turn to east by south near Pitzewo, north-east of the Dalien (Dalny) Bay. Further south-east these curved axes are remarkably well shown by the successive zonal arrangement of Sinian, Takushan (Wutai?) and Cambrian rocks in the Elliot Islands. More arcuate folds are spread further north. They run through rocks of very different ages, and further, they juxtapose and transpose numerous other elements. Their identity can by no means be easily established. Nevertheless it can hardly be disputed that the disconcerting arrangement of the foremost parts of the double wedge-shaped peninsulas is largely due to the distortion connected with the development of these fold-arcs.

More or less similar in shape and symmetrical in position to the above-mentioned arcs is the Noto Rise in the Sea of Japan. If these are reflex arcs, as they appear to be, of an epsilon structural system, we would expect, by interpolation, the frontal arc of the same system passing along the north-western part of the Main Island of Japan and the south-western part of Korea. This is indeed the case verifiable under extraordinary circumstances in the south-western corner of Korea (Kinosaki, 1929). Along the north-eastern coast of the Chinto Island and around the districts of Heinam and Usuon, South Chongnado, belts of acid tuffs with a plant-bearing black shale probably of Cretaceous age at the base, granophyre and granophyric tuffs, elongated bodies of biotite granite, and numerous dykes, all run south-south-east or south-east. They fling against Mesocathaysian folds formed in quartzites and slates probably of Sinian age and Archaean schist of similar strike which otherwise dominates the country.

From northern Kyushu a belt of old Palaeozoics consisting of phyllites and slates with some marble stretches along the north-western coast of Honshu covering parts of Nagato and Iwami Provinces, another sweeping across Yamashiro, Tamba, Wakasa, and Kaga districts in the Chukoku area, and a third with granite forming its axial core extends from Totomi and Shinano Provinces to the Noto Peninsula. All these leading structural axes tend to turn more to the north as they stretch to the north-east. They cannot be regarded as elements belonging to the Inner Zonal structure of Japan (Richthofen, 1903), for they depart considerably in trend from the " Median Line." It would thus seem natural to accept them as component parts of the required frontal arc.

The backbone of the system is found in the Taipaiksan Range with its eastern flank diving into the Sea of Japan, its western flank being covered, on the eastern side of the Lakdongkang, by Upper Jurassic or Cretaceous shales and sandstones and penetrated by granite porphyries and porphyrites running north-south. Its northern extension reaches north-eastern Korea to the north-west of Songtsin (Songjin), where limestone and dolomite probably of pre-Cambrian age are closely folded together with amazingly long strips of schist, schistose granite and granite intrusions penetrated by aplite, pegmatite and lamprophyres (Kinosaki, 1929) all striking north-south and being traversed by faults running east-west. In the southernmost part of this backbone, i.e. in the Yuchong and Milyang districts, a network of faults with one set running N.36°-40° E., and another N. 36°-40° W. filled by dykes and veins (Tateiwa, 1929) shows that the terrain has been subjected to east-west tension due to vaulting up along a north-south axis.

To the south of this meridional zone of compression somewhere should lie the apex of the frontal arc. This is again verified by the somewhat radial arrangement of the tear-faults running between the Goto Islands off north-western Kyushu. Indeed there appears no conceivable reason but the presence of this epsilon system in the north that can adequately account for the modified arrangement of the Outer Zone as it runs across Kyushu.

III. THE PARA-EQUATORIAL FOLD-ZONES

Much has been written on these rhythmic zones of repeated north-south compression known as (5) the Inshan, (6) Tsinling, and (7) Nanling zones, located in about latitudes 41°-42°, 33°-34°, and 25°-26° respectively. We are here only concerned with their transposed and interposed relation with belts of Meso- and Neocathaysian folds. Because of these relations the latter are rendered into three parallel series of linearly arranged arcs of which the Kurile, Honshu and Riukiu constitute the outer series. The middle series comprises the Tungus arc in northern Manchuria representing the south-western continuation of the Sikhota-Alin axis, the Korean arc of which the south-western part is largely submerged in the Yellow Sea, and the Minnan arc in southern Fukien formed by bending the south-western extension of the Taiyun Range into the trend of the Poping. In this last-named range and in central Manchuria we find only mutilated parts of the para-equatorial fold-zone interposed between the Meso- and Neocathaysians. It is still uncertain as to how the Tsinling Zone behaves in the Yellow Sea. Nevertheless analogical reasoning leads us to believe its presence, even though in a subdued form, in the Yellow Sea area, because otherwise there could not have been a Korean arc so arranged as is suggested by the array of islands off the south-western corner of Korea. The inner series consists of the Yenyuanshan arc which is the south-western extension of the Great Khingan sweeping round and across the Jehol and Chahar Provinces, the Hiongerr-Hiaoshan arc in northern Honan continuing from the Taihang Range and the Miaoshan arc in south-eastern Kweichow, a south-western extension of the Shuehfengshan Range in western Hunan.

These arcs or " coulisse-like fronts " are neither concentric or similar to a supposed old nucleus in Siberia nor have resulted from the awkward amalgamation of " meridional " and " equatorial " elements through the assumed processes (*Uebergreifung* and *Durchgreifung*) connected with *Flankettung*, but are simply due to the flexuous grain of the continental border, the Meso- and Neocathaysian folds, encountering the cross-grain of the continent, the para-equatorial zones.

IV. SHEAR FAULTS AND GLIDES

These homologous or congeneric features are all produced by notable horizontal displacement between the ruptured blocks or terrains. When the fracture consists of a clear-cut plane or a series of closely packed parallel planes and the displacement is considerable, then it may be called a shear fault. It frequently happens however that numerous parallel planes of rupture are involved in a zone of fracture cutting the rocks into nearly vertical slices or even laminae which are often strongly slickensided in the horizontal direction with a tendency to develop foliation, drag and even distortion within each lamina. In some cases the zone of fracture is rendered schistose varying in width from a few to a few scores of metres. Local folding or buckling of strata usually accompanies such a zone. The relative horizontal displacement between the two sides of it need not be great. These are characteristics of a glide. Associated with the main fracture due to a glide sometimes there occur secondary fractures arranged *en échelon* with respect to the former. They range from splay faults (Anderson, 1942) to minute feather joints where the relative displacement between the dislodged masses is essentially rectilinear. If, however, rotation becomes appreciable in any of the ruptured masses, then there will appear in it curvilinear fractures of secondary nature tending to converge toward the direction which agrees with the sense of rotation of the mass in which they occur, with the centre of rotation lying on the concave side of the curved fractures. They have been described as *nu* (ν) and *lambda* (λ) types of structure when they cover large areas (Lee, 1929), and have been recently recognized as brush joints abounding especially in massive arenaceous and igneous rocks.

Two important groups of shear faults and glides occur in the region under consideration: (8) those striking north-north-west, or more specifically N.10°-20° W., and (9) those striking east-north-east, or more specifically N.65°-75° E., always with the plane of glide or fault plane standing nearly vertically. For practical purposes we need not distinguish these two types.

In western Shantung those striking north-north-west appear to be somewhat more prominent than those striking east-north-east. The former run along the Fangho, Sintai-Laiwu and Yishui grabens letting down shales and tuffaceous conglomerate of Cretaceous age against horsts of Archaean, Sinian and Lower Palaeozoic rocks. The horsts are as a rule subdivided into countless blocks by faults running east-north-east. Similarly arranged faults occur in the Shantung and Liaotung Peninsulas and around all the Mioatao Islands. Those running along the Adams Bay evidently extend in about the direction of N.70° E., and join those running north-north-west in the neighbourhood of Pulantien where the Jurassic and Cretaceous rocks probably owe their preservation to these faults. Another remarkable fault of the same type and considerable extension is the one which runs from Pitzewo on the south-eastern coast of the Liaotung Peninsula in the direction of N.20°W. To the west of this line of fracture we find little granite, but to the east of it, granite occurs in abundance. And it is noteworthy that the main body of granite in south-eastern Manchuria is divided into three elongated masses with their northern boundaries all extending in the direction of N.70° E.

In northern Korea large faults striking east-north-east are developed *par excellence*. They form the boundary of the Kalwoong, Dookai, Chuyu Myohiang Ranges, and affect all the formations present in the area, i.e. up to the Permian, with downthrow always on the northern side. Faults striking north-north-west attain importance in the lower Taidongkang, south-west of Pyungyang, where tuffaceous shales and sandstones probably of Cretaceous age are thrown by these faults into contact with either granitoid gneiss or Lower Palaeozoic strata. These faults are best developed in the Kuwolsan, Chaimosan and Yukchunghyen. But towards the north-east and the south they attain much wider distribution. Indeed much of the western and a part of the eastern Korean coast as well as the Chinese coast between southern Shantung and the mouth of the Yangtze are apparently due to the same type of faulting. Hence the origin of the Yellow Sea.

These two groups of fractures, especially the glides, prevail widely to the south of Shanghai. They affect the rhyolite and the volcanic series in Chekiang Province, and sometimes render the schist, according to L. P. Wu and M. T. Lee, turning their plane of schistosity in the zone of glide into the position parallel to the plane of glide. They are so extensively distributed towards the south that important glides trending north-north-west have been observed in north-eastern Yunnan, while faults of the same group play an important rôle in the structure of the Hongkong granite and in determining the coast of the Isle of Hongkong and of the neighbouring mainland.

In Japan the shape and alignment of numerous islands are largely controlled by faults belonging to these two groups. Those trending east-north-east approximately agree with the orientation of the median line of western Honshu and its northern and southern shores. Rows of islands of granite in the Seto Inland Sea are likewise arranged in the same direction. These sub-median lines are run across by another set of faults typically developed in the Hiroshima Bay along the Wakasa, Eda and Nishinomi islands reaching as far south as Matsuyama on the northern shore of Shikoku. Similar faults are probably present in north-western Kyushu traversing in the Mesozoics and between Kyushu and Shikoku.

Most impressive of all is the line of andesitic eruption running along the so-called Fossa Magna (Naumann, 1885) and reaching as far as the Sulphur Islands with a large number of volcanic islands dotted along it. It is of interest to note that the main axis of south-western Japan trends at first north-east, then north-north-east and finally even nearly north as it approaches the western border of Fossa Magna or the Itoigawa-Shizuoka line of Yabe (1929b), and that on the eastern side of Fossa Magna the Kwanto Mountain land, apparently a continuation of the Outer Zone of south-western Japan, assumes a general trend varying from east-south-east to south-east and extending in the direction of the Choshi Promontory. Thus the conditions on the western side of Fossa Magna suggest a lateral

drag and those on the eastern side splay fractures. They all agree to show that the land on the western side slipped to the south. More notable examples of glide running obliquely to the continental border are the one which lies diagonally across Hokkaido on the western side of the orogenic belt, and those which pass along the southern coast of the fin-like peninsulas and then across the main body of the fish-shaped island of Sakhalin. Andesitic flows mark the lines of rupture which in these cases are buried by the Tertiary deposits.

If we compare these glides of considerable extension and violent nature, noting especially the trend of the gigantic one cutting right across central Japan and stretching far into the Pacific, with those deeps, one of which significantly strikes the point of greatest bending in the south-western part of the Riukiu arc and extends to the south-south-east, and another occurring on the eastern side of the Philippine Islands, it seems difficult to deny the probability that these too are due to fractures of similar origin.

Some of these glides apparently date back from pre-Tertiary times. Others no doubt originated during the Tertiary. There are again those in which movements are evidently still active; for some of the zones of intense earthquake in historical and recent times either coincide with them or agree with them in trend. By plotting the localities of violent earthquakes which have occurred in eastern China during historical times, C. C. Wang has admirably shown the presence of such an active zone stretching from south-western Shantung nearly to the north of Nanking, being parallel to the coast of northern Kiangsu. Another notorious active zone occurs along the Wakasa-Nishinomi line to which reference has already been made.

V. JOINTS AND THEIR COGNATE FAULTS, CLEAVAGE AND PSEUDO-CLEAVAGE

The study of the minor structures in the region under consideration has not advanced far afield. Those which have been made known more or less systematically in the southern part of Sinokorea fall into seven groups or sets: vertical or highly inclined joints and faults striking (10) N.10°-20° W. and (11) N.65°-75° E. are often closely associated with (12) those running north-south and (13) east-west, and sometimes with cleavage, pseudo-cleavage and joints striking (14) N. 75°-80° W., and (15) N.5°-10° W., only rarely with (16) those striking N.15°-22° E. The results of a statistical study by T. C. Sun and C. H. Cheng on these elements in two areas on the coast of Chekiang are embodied in the two diagrams attached to the accompanying map being placed as nearly as possible to the localities to which they refer.

If the origin of the Neocathaysian seas can be justly regarded as part of the entangled development of this structural complex, the problem of the former would be ultimately reduced to one of analysis of the latter, and would therefore inevitably touch, as most tectonic problems do, upon the field of geo-mechanics—a subject some may prefer to call tectonophysics in spite of its more pretentious if not less euphonious nature. And in any such analysis three important points must be kept in view. First of all, lineament tectonics in the sense we have used here can hardly be of any real value unless the stresses involved act essentially in the horizontal plane. Fortunately this is the case; for it can be readily shown from the condition of equilibrium, that in any part of a deforming, thin, spherical or nearly spherical shell such as the superficial layer of the earth's crust with which we are dealing, the vertical component of the operating stress is always negligibly small as compared with the horizontal ones whatever the origin of the deformation. Secondly, a structural element must be treated in its proper tectonic order; for an element produced by the primary stress operating in a region often fundamentally differs in its mechanical character from that produced by stresses aroused as a consequence of the deformation or dislocation due to the primary stress and so on. The network of faults, for instance, present in the southern part of the backbone of the Liaohan epsilon are, for the reasons already stated above, clearly of second tectonic order. Thirdly, evidence has been brought forward to show that relaxation of stress has actually taken place in elastically deformed rocks in nature (Lee, 1942 and 1946a). This means that the limit, as usually accepted, of the so-called fundamental strength of rocks (Griggs, 1939 and 1940) must be considerably lowered or even nullified

when they are subjected to sufficiently long duration of loading such as attained in their natural state of deformation. This last point makes it worth while considering certain experiments with clay (Chen and Lee, 1948; Lee, 1948) in connexion with the treatment of the problem in hand.

By subjecting blocks, cylinders, beams and layered cakes of clay to various methods of loading, it has been demonstrated that Lüders' lines and other shear fractures appear in the clay tested in such a way that the acute angle contained between each pair of shear planes is bisected by a line which always agrees with the direction of the compression or lies at right angles to the direction of tension; and that in the case of distorted cakes of clay unevenly attached to an inclined board or a rotating disc the distorted pattern of the folds of the epsilon type is always so oriented that the convex front of the fold-arcs always faces the direction in which the differential forward movement takes place in the clay-cake.

Now we may inquire into the nature of the stresses or the type of tectonic movements which are primarily responsible for the birth of the Neocathaysian seas. Simple tension with consequent rifting such as may be postulated in connexion with Wegenerian drift is obviously out of question. Pure shear along the continental border seems suggestive, but it cannot fall in line with the shear-net laboriously constructed by F. A. Vening-Meinesz (1947). For, if it does, the splay glides on the Pacific side would be oriented more to the south-west, and the para-marginal folding could not have been so intense and so widespread on the continent. The glides and shear faults as described in groups (8) and (9) and their related joints, groups (15) and (16), belong without much doubt to the Neocathaysian system. From experimental evidence alluded to, these shear fractures and the large apposite faults running at right angles to the south-eastern Chinese coast would necessarily result if the border of the continent was subjected to Neocathaysian compression. Since it is an established fact that such compression is not restricted to the Neocathaysian, but was preceded by the Mesocathaysian folding, it appears highly probable, also from experimental evidence, that these compressive features are of second tectonic order resulting from a continued southward movement and consequent distortion of the eastern Asiatic continent against the Pacific floor. This agrees with the arrangement of the Meso- and Neocathaysian and even the revived Cathaysian folds, the splay glides on the Pacific side spreading from the Sakhalin to the Philippines, and the intermittent activity of stresses within the framework of the epsilon structures (Lee, 1946b) since the end of the Jurassic period. We are thus enabled to see that the disturbances were largely initiated from the continental side.

At any rate the several classes of structural features that characterize the border of eastern Asia together with the seas fringing it can in no way, except for partial agreement in age, be compared with the Cordilleras and their engulfed waters on the eastern side of the Pacific. If that grand orogen may claim its parallel in Asia it is probably to be found in the Sikang-Yunnan-Burma geosyncline now turned over to an orogen of equally impressive nature.

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DISCUSSION

C. A. E. O'BRIEN welcomed the author's use of soft clay in orogenic experiments. He thought many people still held wrong views, using more rigid materials in model construction, and asked for more discussion of this difference.

RESEARCH IN SUBMARINE GEOLOGY SPONSORED BY THE U.S. NAVY

By R. DANA RUSSELL

U.S.A.

ABSTRACT

The U.S. Navy Department, particularly through the Hydrographic Office, the Bureau of Ships, and the Office of Naval Research, has been and is continuing to participate in research in submarine geology and oceanography to a notable extent. This participation consists of: (*a*) contracts and co-operative agreements with universities, private research institutions, and other government agencies; (*b*) direct contributions by Navy activities in connection with certain types of survey work, acoustic research, and training operations. Most of the information thus accumulated is in the process of publication.

Examples of the type of research and data obtained include: compilation of available data on bottom character in shallow water (less than 100 fathoms) and publication of " Bottom Sediment Charts " showing this information; compilation of additional soundings and publication of new bathymetric charts; detailed bottom surveys (with many samples and bottom photographs) of particular areas, in connection with acoustic research, with submarine installations such as SOFAR, and with the Bikini tests: collection of samples, cores, and fathograms from the deep sea and from submarine banks in the Antarctic, Arctic, the western Atlantic, Gulf of Mexico, and eastern Pacific; development of new equipment for bottom surveys.

INTRODUCTION

IT is a truism in the modern world that the Navy of a major power, if it is to maintain itself in a state of readiness, must devote a considerable effort to research in the fields of communication, detection, ship design, and ordnance. It is not quite so obvious why the United States Navy should be involved in research in submarine geology. There are two reasons. First, the operation of Naval vessels provides opportunities to collect oceanographic and submarine geological data at little or no additional cost. Second, and more important, the Navy is acutely aware of the need to increase our fund of basic scientific knowledge. Knowledge of the sea is particularly important, since to-day's " pure science " may yield data of operational value to-morrow.

Accordingly, the Navy Department of the United States is sponsoring research in submarine geology in several ways. It is contributing directly to submarine geological research by conducting surveys of specific areas, and is collecting additional oceanographic and geologic data in connection with acoustic research and with training operations. In addition, the Navy sponsors research in submarine geology through contracts and co-operative agreements with universities, private research institutions, and other Government agencies. The agencies of the Navy Department engaged in this sponsorship are chiefly the Office of Naval Research, the Hydrographic Office, and the Bureau of Ships. Practically all of the work so sponsored, though largely classified as confidential or secret during the war, has been de-classified in accordance with the Navy Department's policy of releasing information of basic scientific value. Most of the work done during World War II has been published or is in process of publication, and the work being done at present is also resulting in publications in various professional journals.

The interest of the Navy extends all the way from studies involving the compilation and analysis of existing data to the support of fundamental research projects. It is not my purpose to list all of the research projects sponsored by the United States Navy, or to describe any one of them in detail. Rather, I wish to present here a few selected examples of the types of research which have been sponsored by the Navy, primarily for the purpose of directing the attention of submarine geologists to the results which have appeared or which may be expected to appear in professional journals.

COMPILATION AND ANALYSIS OF EXISTING DATA

During World War II, one of the projects which engaged a number of geologists was the compilation of all existing data on the character of the continental shelves in certain areas. This compilation resulted in the production of a considerable number of charts showing the character of the bottom. Forty-three " Bottom Sediment Charts " were prepared by the University of California Division of War Research for areas along the Asiatic Coast and Dutch East Indies; 25 of these charts were printed by the Hydrographic Office (Shepard and Emery, 1946a). Others, prepared at the Woods Hole Oceanographic Institution, covered parts of the Atlantic coast of the United States and small portions of Atlantic coasts of Europe and Africa. Though some of these compilations included information of military importance and hence have not been released, a number of them have been made available to the public. They represent the first detailed compilation of existing information on the character of the continental shelves down to depths of 100 fathoms.

A second example of work of this type is the very valuable chart of the north-west Pacific compiled by Hess (1948). Hess' work provides a new framework for understanding the structural behaviour of a large and active portion of the earth's crust.

SURVEYS

A second type of research activity in which the Navy is engaged consists of both detailed and reconnaissance surveys of specific areas. Some of these surveys have been made in connection with acoustic research, some were made in connection with the installation of special underwater equipment, others were made in connection with special tests, and still others were undertaken to assist other Government agencies.

Topographic and Geologic Surveys.—In shallow water, the character of the bottom has a notable effect upon the propagation of underwater sound. In conducting research in underwater acoustics, it is therefore necessary to chart the character of the bottom in some detail. The area off San Diego, for example, has been carefully mapped by the University of California Division of War Research and by the Navy Electronics Laboratory. Adjacent areas have also been surveyed and some of them have been described (Emery, 1948).

The installation of electronic equipment on the sea floor also requires a careful determination of the topography and character of the bottom. For example, the installation of a series of underwater hydrophones for a SOFAR network in the north-east Pacific by the U.S. Navy Electronics Laboratory required charting of bottom areas in the vicinity of Monterey and Point Arena, California, and of Kaneohe and Hilo in the Hawaiian Islands.

One of the most detailed submarine geological surveys ever made was done in connection with the atomic bomb tests at Bikini (Emery, 1946; Tracey, Ladd, and Hoffmeister, 1946; Revelle, 1947). A closely-spaced net of sonic soundings covered Bikini lagoon, with numerous lines on the outer slopes of the atoll. Several thousand bottom samples, cores and underwater photographs were taken in the lagoon and adjacent areas. The resulting topographic and bottom character charts of Bikini, soon to be published, will furnish our first detailed picture of the surficial characteristics of a coral atoll. In addition, the internal character of the atoll was explored by means of five holes drilled on Bikini Island, the deepest to a depth of 2,556 feet (Ladd, Tracey, and Lill, 1948). The sediments encountered (porous limestone and calcareous sand) were determined to be definitely Tertiary below 930 feet, and the Tertiary boundary may be as high as 425 feet. The bottom of the deep hole ended in early Miocene, apparently equivalent to Tertiary *e* of the East Indian section. Dolomitization, a striking feature of the lithology at Funafuti, is absent in the Bikini borings. An additional drilling programme is now being promoted by the Geological Society of America, the United States Geological Survey, and the Office of Naval Research. The intent of this programme is to drill one hole to a depth of at least 8,000 feet in an attempt to penetrate the basement, which a refraction seismic survey conducted by Navy geophysicists (Dobrin, *et al.*, 1946) indicates to be at depths between 6,000 and 13,000 feet. Additional shallow holes will be drilled on other islands of the atoll if time and funds permit.

Half of the $200,000 required for this purpose has been guaranteed by the Geological Society of America and the Office of Naval Research provided the remainder is obtained from other sources. This deep drilling programme, if carried out, should yield invaluable information on the geology of a typical coral atoll, as well as key information on the general geology of the western Pacific basin.

An example of the type of assistance provided by the Navy to other Government agencies is furnished by the Lake Mead project. This is a co-operative survey of Lake Mead to determine the amount of sedimentation that has taken place in the lake basin since the erection of Boulder (now Hoover) Dam on the Colorado River in 1936. In co-operation with the Bureau of Reclamation and the U.S. Geological Survey, a detailed chart of the lake bottom is being prepared, using the latest echo-sounding techniques. Oceanographic measurements are being made to determine the heat budget of the lake, with bottom samples and cores to determine the character of the sediments. The Bureau of Ships, the Bureau of Ordnance, and the Navy Electronics Laboratory are all participating in this work.

In addition to detailed surveys of the types listed, a number of reconnaissance surveys have been made by the Navy or sponsored by the Navy in co-operation with other institutions. For example, in connection with the Bikini survey, the atolls of Eniwetok, Rongelap, Rongerik and Ailinganae were surveyed in fair detail, and reconnaissance data were obtained over a large area in the western Pacific. This information will also be published, along with the detailed survey of Bikini atoll, in a monograph being prepared under the direction of the United States Geological Survey.

Another example of reconnaissance mapping of the bottom is furnished by Operation Highjump, the Navy expedition to the Antarctic in early 1947. Dr. Hough of the University of Illinois is working on the sediment samples collected by this expedition and will soon have a chart of bottom topography and sediments ready for publication. In addition to Operation Highjump, the Navy, through the Office of Naval Research, also sponsored the Finn Ronne expedition to the Antarctic in 1947-48.

Geophysical Surveys.—A number of geophysical surveys of a reconnaissance nature have also been sponsored by the Navy. The seismic survey of Bikini Atoll was mentioned previously. Airborne magnetometer surveys have been made by Navy planes in the Aleutians and at Bikini, in a joint project sponsored by the Office of Naval Research, the Naval Ordnance Laboratory and the U.S. Geological Survey. Also, during the summer of 1947, a co-operative programme between the Office of Naval Research and the U.S. Geological Survey resulted in a gravity survey of approximately 3,200 square miles of the continental shelf of the northern Gulf of Mexico. The resulting map shows a number of circular to oval structures, presumably salt domes, many of which do not have any surface expression. These domes are farther off-shore than the area surveyed in detail with gravity and seismic methods by some of the Gulf Coast oil companies.

In addition to these surveys on the continental shelf, the Office of Naval Research is supporting Dr. Maurice Ewing of Columbia University in a programme of gravity surveys from submerged submarines throughout the oceans. Surveys have already been made off the east coast of the United States, in the Caribbean, and in the deep trough off western South America. The Navy has also sponsored some of Ewing's work on explosive sounding and seismic techniques (Ewing, et. al., 1946), which have yielded valuable data on the thickness of sediment on the continental shelf and slope off the Atlantic coast of the United States. Similar work is also being undertaken by Dr. Raitt of the Marine Physical Laboratory of the University of California, under contracts with the Office of Naval Research and the Bureau of Ships.

COLLECTION OF MISCELLANEOUS DATA

Navy scientists, and private scientists on Navy ships, are also collecting much miscellaneous data on submarine geology. Cores, bottom samples, and bottom photographs are being collected regularly from the eastern Pacific and from portions of the Atlantic. Some of the data to be expected from the study of such samples and cores are exemplified by the work of Dr. Ellis Johnson of the Department of Terrestial Magnetism, Carnegie Institution of Washington, and Dr. W. D. Urry of the Geophysical

Laboratory. Using the method of Piggot and Urry (1942), for age determinations, Urry and Hough report* that a core collected from the Ross Sea during Operation Highjump shows glacial marine deposits of Kansan and probably of Nebraskan age, with well-sorted interstratified inter-glacial deposits, probably of Yarmouth and Sangamon age. This core suggests essentially contemporaneous glaciation of the northern and southern hemispheres. A second core, collected off western South America, does not show this relationship, but instead has at least 30 alternating layers of globigerina ooze and red clay, with a total age of about half a million years. Johnson has determined the changes in the direction of the horizontal component of the earth's magnetic field for the past half million years from this core, and has found variations of as much as 30 degrees in this component.

Fathograms taken during some of these expeditions and during regular trips by Navy vessels are also yielding interesting data. For example, new information on submarine canyons has become available (Shepard, 1946, 1948). Also, fathograms taken by Dr. Dietz (1948a) aboard the *USS Henderson* during Operation Highjump have revealed the existence of five sea mounts not previously known, as well as furnishing additional data on the character of the Easter Island Swell and of the continental slope and shelf of Antarctica. Of the new sea mounts discovered, four are in the abyssal ocean off the coast of lower California, and a very large one was discovered in the south-west Pacific about 1,000 miles west of New Zealand. In contrast with the sea mounts described from the north-west Pacific by Hess, none of these sea mounts showed a truncated summit and only one showed the possible existence of a terrace, though several rise above 800 fathoms. Fathogram profiles of the continental slope of Antarctica showed, in contrast with the continental slopes of most of the continents, a profile that is remarkably long, smooth, and gentle. The slope varies from 2 degrees, near the top, to about one-fourth of one degree at the bottom where, 150 miles out from the continental shelf, the slope fades into the abyssal sea floor. The smoothness and concavity of the slope suggests that it has been extensively modified by sedimentation. The top of the continental slope is marked by a sharp break at a depth of 280 fathoms, with the deep but level continental shelf extending shoreward. This change from shelf to slope at 280 fathoms contrasts with the usual break off most continents at a depth of about 72 fathoms.

A second continental slope profile was obtained when the *Henderson* ran up the continental slope of Southern Australia into Bass Strait, between Australia and Tasmania. The lower portion of this slope is irregular and hummocky, with an abrupt change in slope at 500 fathoms. The lower portion of the slope has a declivity of about 2 degrees; the top portion has a declivity of 6 degrees. The break in slope between the continental shelf and slope occurs at about 80 fathoms.

One of the interesting features of the many fathograms being taken by Naval vessels is the almost universal presence of a " false " or " phantom " bottom (Lyman, 1948; Dietz, 1948b; Eyring, et al., 1948). Although not strictly a geological phenomenon, this layer, sometimes called the " deep scattering layer," is now known to occur from the Mediterranean to the western Pacific, and may account for many reported banks which have never been found upon re-survey. This phenomenon is believed to be caused by the scattering of sound by a layer of organisms because the layer ascends to the surface shortly after sunset and descends again shortly before sunrise. The organisms which may produce the " phantom bottom " have not been identified, however. The reporting of shoals based upon the return of echoes from this deep scattering layer illustrates one of the many difficulties encountered in attempting to construct accurate charts from data sent in by untrained observers. The Hydrographic Office of the Navy is attempting to train observers on both Navy and civilian ships so that more accurate data may be obtained for the construction of charts and is also trying to collect accurately located fathograms and soundings from merchant ships as well as from Navy vessels. The compilation of this information over the period of the next few years will vastly expand our knowledge of the topography of the ocean bottoms.

*Personal communications.

It is hoped that additional geological data will be obtained when the north-east Pacific SOFAR network is established sometime this year. SOFAR (for SOund Fixing And Ranging) is a system that utilizes a deep zone in the ocean for the transmission of sound over long distances. When sound is generated in this deep sound channel, as by a small bomb detonated hydrostatically, a large part of the energy is confined to the channel by refraction, so that the sound is transmitted for hundreds to thousands of miles with minimum loss of intensity. Bombs dropped off Dakar, for example, were heard at Eleuthera in the Bahamas, 3,100 miles away (Ewing, et. al., 1946a). Accurate determination of the time of arrival at three or more stations permit location of the source of the sound by differences in arrival times. Designed primarily for the rescue of survivors at sea, SOFAR also offers a new approach to the solution of several oceanographic and submarine geological problems. For example, sea mounts and other submerged topographic highs may be located in some cases by the acoustic shadows cast by them, and it is also possible that submarine volcanic eruptions may be located by the sounds emitted. An earthquake originating near the SOFAR installation at Point Sur, California, has recently been recorded on the submarine hydrophone installed there. In contrast to the usual SOFAR bomb signal, which builds up slowly to maximum intensity and then abruptly drops off, the earthquake signal showed an initial high intensity and then a gradual decrease. When the SOFAR network is in operation, each station will be monitored continuously, so that additional data of this sort will be available and may provide new information on earthquake waves.

EQUIPMENT DEVELOPMENT

Several types of new equipment for determining the character of the ocean bottom have been developed as a by-product of Navy-sponsored research (Ewing, *et al.*, 1946a; Emery and Champion, 1948; LaFond and Dietz, 1948). These include new types of " grab " samplers, one of them for use from a ship underway, equipment for photographing the bottom, (Ewing, *et al.*, 1946b; Shepard and Emery, 1946b), and new types of acoustic equipment. A hydrophone, adapted for dragging over the bottom, gives valuable data on the type of bottom from the kind of sounds produced. The " bottom scanner," a new type of echo sounder developed by the University of California and the Navy Electronics Laboratory, presents a profile of the bottom below the ship on the face of a cathode ray oscilloscope tube (Russell, 1946b). This device was used at Bikini for locating coral knolls, and several are now being manufactured for use by the Hydrographic Office.

OTHER RESEARCH PROJECTS

Finally, the Navy is sponsoring a number of projects which do not readily fit into any of the previous types described. Examples are Dr. Phleger's foraminifera laboratory, financed by a contract between the Office of Naval Research and the Woods Hole Oceanographic Institution and devoted to the study of recent foraminifera, and the fundamental studies on waves (Munk and Traylor, 1947; Munk, 1948) underway at the Scripps Institution of Oceanography, the University of California at Berkeley, and the Woods Hole Oceanographic Institution under contracts with the Office of Naval Research and the Bureau of Ships. Some of the work on long period waves (periods of 15 minutes and more) at the Scripps Institution (Munk, *et al.*, 1948) is of particular interest to submarine geologists, since a study of these waves may show that bottom currents are generated at greater depths than was previously believed possible, and hence may cause revision of present concepts of the depths at which sediments can be moved. The Office of Naval Research and the Bureau of Ships are also sponsoring detailed studies of the movement of sand on beaches (Shepard, 1948). This work is also being done at the Scripps Institution and at the University of California at Berkeley.

These examples demonstrate a few of the types of research in submarine geology in which the United States Navy is actively interested. If the Navy's sponsorship continues, as there is reason to believe that it will, we can look forward to tremendous advances in our knowledge of the geology of the ocean basins within the next few decades.

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DISCUSSION

N. B. WILSON asked the author to discuss the criteria used in correlating the age of glacial deposits of submarine character in the Antarctic with those of Kansan and Nebraskan age in the northern mid-continent area of the U.S.A.

R. D. RUSSELL replied that the method used by Urry and Hough to determine the age of cores from the South Pacific had been described by Piggot and Urry (*Bull. Geol. Soc. Amer.*, 53, pp. 1187–1210, 1942).

PH. H. KUENEN asked whether there were submarine canyons on the Antarctic continental slope.

R. D. RUSSELL referred the question to R. S. DIETZ who replied that a few examples of depressions in the continental slope were found but insufficient appropriately located soundings were obtained to be certain that these were canyons. In general the Antarctic continental slope appeared to be surprisingly smooth and lacking in irregularities.

NORDSEE UND NORDMEER ALS AUSSICHTSREICHSTES GEBIET FUER GEOLOGISCH-GEOPHYSIKALISCHE MEERESFORSCHUNG

Von R. SCHWINNER
Austria

ABSTRACT

Die Geologie der Meeresboden arbeitet mit Extrapolation vom Festland und geophysikalischen Methoden. Zum ersten ist guenstig geringe Ausdehnung. Die Nordsee, ein kontinentales " Feld " (Cloos) ist einfach Fortsetzung der westdeutschen Tiefebene, das Nordmeer wohl ein ozeanisches " Feld," aber eins der kleinsten. Geophysikalische Daten sind geologisch mehrdeutig. Aber in diesem einheitlich, kaledonisch, umrahmten Raum kann der Geologe seine Fragen *eindeutig auf*: *entweder—oder* stellen: A) Fixismus—Kontinentenwanderung (Wegener); B.) Kaledonische Gebirgszusammenhaenge: Norwegen—Schottland, Ostgroenland—Acadia, *oder*: Norwegen—Pompeckjsche Schwelle—Sudeten, Ostgroenland—Islandschwelle—Schottland.

Arbeitsplan, *Geologisch* sind die Kuesten ziemlich bekannt, gewisse Ergaenzungen wuenschenswert *Geodaesie*: Groenland, Faroeer angeblich wandernd? *Lotung*, *Bodenproben*: das Relief des Ozeanbodens ist unmittelbar tektonisch bestimmt, das Flussnetz (als die Nordsee trocken lag) mittelbar. *Magnetische Uebersichtsaufnahme*: gibt Fingerseige fuer weiteres. *Schweremessung* entscheidet ueber die Gebirgszusammenhaenge (Schottische und Norwegische Gebirge muessten neu vermessen werden). *Mikroseismen* zeigen Gebirgszusammenhaenge (Schwinner). *Sprengseismik* gibt Detailtektonik der Kuesten, etwa ob vor Norwegen ein " borderland " versunken ist an junger Verwerfung (Holtedahl). *Fernbebenbeobachtung* entscheidet ueber Wegener: ob mitten im Nordmeer Sima blossliegt wie im Pazifik?

DROWNED ISLANDS AND ORIGIN OF THE OCEANS

By R. A. SONDER

Switzerland

ABSTRACT

The recently discovered drowned islands in the Pacific (Hess, *Amer. Jour. Sci.*, 772, 1946) suggest a secular deepening of the oceans indicating eventually the existence of a secular earth contraction (Sonder, *Trans. Amer. Geophys. Union*, 943, 1947). The continents are the scars of past orogenic unrest indicating the sites of crustal surface reductions. The ocean floors represent the unchanged old crust covered by secular sedimentation in variable thickness (5-20 kms.) with faulting zones like the Mid-Atlantic ridge and isolated volcanic cones caused by crustal splittings during major tectonic paroxysms. Vapor disengaging from crystallizing magma and the secular surface reduction of the contracting earth caused a secular deepening of the oceans, drowning dead volcanic cones the deeper the older they are. In younger epochs coral growth could compensate the slow drowning. Due to the cyclical nature of tectonic unrest manifested too in preferred ages of radioactive minerals (Holmes, Kuenen, Wahl), the top of the drowned islands should stand, according to this explanation, on preferred levels. A statistic of known top levels seems to confirm this conclusion and thereby the proposed explanation.

SOME PROBLEMS OF MANGANESE NODULES

By Z. SUJKOWSKI
Poland

ABSTRACT

The results of recent researches on the character, structure, chemical composition and origin of manganese nodules are presented. My study of the relation between the nodules and their environment indicates that they are independent of the bottom sediments but dependent on the sea water.

The quantity of rare components is larger than it was previously known, the role played by nickel and copper especially was carefully investigated and some relation of both these constituents to the depth seems to be established.

The relation of deep-sea nodules to shallow-water ones is discussed and the conclusion is reached that they are related but not identical phenomena.

The presence of organic matter in the nodules is twice as great as in the surrounding sediments; this serves as a basis for a hypothesis of organic origin of nodules. Some iron bacteria deposits are examined and their analogy with, and difference from, nodules indicated.

Manganese nodules are most likely due to the activity of certain lowly organisms, not necessarily bacteria.

Finally, recent nodules are compared with possible fossil analogues.

MARINE TERRACES OF THE PACIFIC OCEAN AREA

By A. C. TESTER

U.S.A.

ABSTRACT

Observations made in several of the island groups of the Pacific Ocean area during military service confirm the presence of terraces or benches at uniform levels, that can be correlated in an area of over 20 million square miles.

This report is based on studies of terraces and benches from New Zealand to Japan and from Hawaii to the Philippines and submits detailed measurements and observations from New Caledonia, New Hebrides, Solomon group, Marianas group and Japan. Checks were made on previous work in other island groups and the benches correlated with the areas described in detail. The evidence for marine formation of benches is described and illustrated with photographs of the various physiographic features. Comparison of bench elevations in New Caledonia, Marianas group and Hawaiian group shows that at least eight levels can be correlated. These levels are at 5-6 feet, 25-28 feet, 65-70 feet, 90-100 feet, 245-250 feet, 325-330 feet, 375-380 feet, and 565-580 feet above present mean sea-level. Numerous other levels were mapped in New Caledonia and Tinian, Marianas group, and some are well developed, but the eight named above are characteristically prominent in most of the Pacific islands of appropriate elevation.

The cause of uniform elevations of benches in such widely separated areas is considered. The influence of Pleistocene glaciation is discarded as being inadequate to produce the quantity and regularity of change. The evidence indicates that most, if not all, of the benches were formed by successive movements which lowered sea-level without intervals of resubmergence and that each new level was accomplished in a short time. The only plausible explanation of the development of eustatic benches known at this time is found in a hypothesis of oceanic basin subsidence. Data to support such a hypothesis are not abundant and some facts are only suggestive.

DISCUSSION

P. Marshall said that recent movements of the coastline in New Zealand had been associated with definite earthquake action. He asked the author whether he had made allowances for recent movements in his correlation of marine terraces.

A. C. Tester replied that no terraces had been used from New Zealand, only from New Caledonia. However, if such changes had taken place, there remained certain constant differences to be explained. At Tinian, for instance, wave-cut cliffs had been displaced by faulting but the intervals were constant.

M. Ongley added that the evidence in New Zealand shows that there was not only a New Zealand pattern of coastal benches but also a major Pacific pattern as set out in this paper.

He said that before accepting a six-foot bench, evidence of the tidal range and storm tides was required. New Zealand evidence indicated that storm tides were cutting benches at more than six feet and such did not indicate uplift.

A. C. Tester replied that Pacific tides were very low. At Tinian for example a maximum of two and a half feet obtained.

A. Heim pointed out the difficulty of correlating the E. Sunda Isles with volcanic and diapiric uplift.

THE ORIGIN OF DEEP-SEA TROUGHS IN THE EAST INDIES

By J. H. F. UMBGROVE

Netherlands

ABSTRACT

The island-arcs and troughs of the western part of the East Indies are arranged in parallel rows. Two structural zones, represented by two series of elongated submarine troughs, are inaccessible to direct geological observation. However, a comparison of the structural zones of Burma with those of the East Indies furnishes an important clue concerning the origin and subsequent history of the East Indian deep-sea troughs. Uncertain factors inherent to a correlation which is based on geological features can be eliminated by taking into account also the gravity field of the areas under discussion.

From such a comparative study it appears that the East Indian deep-sea troughs have their counterpart in similar furrows on the continent which, however, were filled up with sediments and eventually raised above sea-level.

Moreover, it appears that the deep-sea troughs originated as subsiding furrows either in the early Tertiary or in post-Miocene times. At any rate they were rejuvenated and enlarged in post-Miocene times. Whether a subsiding area appears at the surface as a depression or not depends mainly on the relation between subsidence of the bottom and supply of detritus from the adjoining areas. In the same way a more internal zone of troughs is represented either as a land area or as a shallow sea bottom or as a deep-sea furrow. As a matter of fact, all the structural zones appear partly above sea-level, partly as submarine features.

INTRODUCTION

IN the western part of the East Indies several structural zones can be clearly recognized. They have their counterpart in more or less similar zones on the Asiatic continent. Two of the East Indian zones are represented by two parallel series of elongated submarine troughs, whereas similar subsiding furrows were filled up with sediment and subsequently raised above sea-level in Burma.

Hence a comparative study between the two areas should furnish some indication concerning the origin and subsequent history of East Indian submarine regions which are inaccessible to direct geological observation. The value of our conclusions concerning this question largely depends on the validity of the suggested correlation between Burmese and the East Indian structural zones. Therefore this topic has to be treated first. Until recently, more than one interpretation was possible as to the correlation between Burmese and East Indian structural elements, owing to the fact that gravimetric data were available from the latter region only. However, since the results of a gravimetric survey of Burma were published by Evans and Crompton in 1946, the gravity fields of both areas can be taken into account.

STRUCTURAL ZONES OF THE EAST INDIES

Proceeding from the south-west towards the north-east the following structural zones can be recognized in the western part of the East Indies.

I. The islands west of Sumatra, belonging to a non-volcanic belt, in which folding occurred in several epochs. A strong Laramide phase was succeeded by two Miocene phases of diastrophism, the most recent one in the Upper Miocene (Tertiary f_2 of the stratigraphic column). A still younger phase of movement—though not of folding—took place in the Upper Pliocene and Lower Pleistocene. As a result of these movements marine sediments of Upper Tertiary age as well as Pleistocene reef limestones, resting unconformably on the older strongly folded strata, were raised above sea-level.

From the islands west of Sumatra this zone continues as a submarine ridge as far eastward as

the island Sumba, where the belt is interrupted, only to appear again east of Sumba running over the islands Rotti and Timor.

In the Moluccas the continuation of this zone coincides with the Mesozoic Banda geosyncline. Coinciding with this zone is the strip of strongly negative anomalies of gravity.

IA. In between zones I and II is a series of elongated deep-sea troughs.

IB. Another series of elongated troughs extends along the external side of zone I. Generally they are called marginal deeps.

Both the IA and IB troughs are intimately connected with zone I from a morphological as well as from a structural point of view. This question will be treated in a following section.

II. The geanticlines of western Sumatra, South Java and the Lesser Sunda Islands bear a conspicuous girdle of volcanoes. Moderate folding took place in the Upper Miocene (Tertiary f_2).

The island Sumba is intermediate between zones I and II not only in respect of its site but also regarding its geological history. Moderate folding in the Miocene and the Tertiary volcanics forms two points of resemblance to zone II. But in its lack of recent volcanoes Sumba resembles more zone I. As was already mentioned, the submarine continuation of zone I is interrupted west of Sumba only to continue again eastwards in the row of islands of the outer Banda Arc. In the same way both the deep-sea troughs of the IA and IB type are interrupted east and west of Sumba.

Remarkably enough the zone of strongly negative anomalies of gravity is also interrupted near Sumba. An attempt to explain these facts will be made in a following section.

III. Along the concave side of the geanticline is a series of ideogeosynclines, which can be followed as an interrupted series of Tertiary oil-bearing troughs over the eastern part of Sumatra and the northern part of Java. Parts of these troughs are below sea-level, viz., in Atcheen (North Sumatra) and in Madura straits. In North Sumatra the downward movement started in the Eocene. Other troughs, like those of Java and Mid-Sumatra originated in the Miocene, after the Miocene epoch of diastrophism. In both cases folding of the accumulated material took place towards the end of the Pliocene. In the eastern part of Java the folding was probably more recent still (Mid-Pleistocene).

IV. A separate zone comprises the pre-Tertiary folded area of Malaya, Banda, Billiton, the Riouw Archipelago and part of Borneo, including the area of the South China Sea and Java Sea. Variscan and early Kimmerian folding may be mentioned as characterizing the structural history of this area, at any rate of large parts of it. The greater part of this region was an area of denudation during most of Mesozoic and Tertiary times.

It was demonstrated by Rutten that clastic material in Upper Tertiary strata of the Javanese sedimentation troughs derived from former land areas in the present Java Sea. The pattern of drowned rivers, as revealed by the bathymetric charts of the Java Sea, South China Sea and Malakka Straits, is generally regarded as Pleistocene in age.

STRUCTURAL ZONES OF BURMA

The structural elements in the East Indies can be recognized very clearly in Burma.

I. Evidently the continuation of the belt of strongly negative anomalies which follows the submarine ridge south of Java and thence runs over the islands west of Sumatra appears again in Burma. Evans and Crompton found a gravity minimum coinciding with the Arakan Yoma, the mountain belt separating the Tertiary areas of Assam and Bengal from those of Burma. The Arakan Yoma was folded towards the end of the Mesozoic (Laramide phase). The same epoch of compression was recognised in those East Indian parts of zone I where both Mesozoic and Tertiary strata are exposed. However, in several parts of the East Indian sectors of zone I marine sedimentation was renewed during the Tertiary. It is not quite clear whether the same applies to the Arakan Yoma. For, according to Chhibber (1934, p. 215) " The belt remained an ever rising geanticline ", whereas Sale and Evans (1940, p. 360) came to the conclusion: " There seems to be no evidence of an effective barrier between Assam and Burma during the Eocene " and: " The subsequent uplift and denudation along the Arakan Yomas, and the paucity of evidence from this little-known region, make it impossible to be sure whether

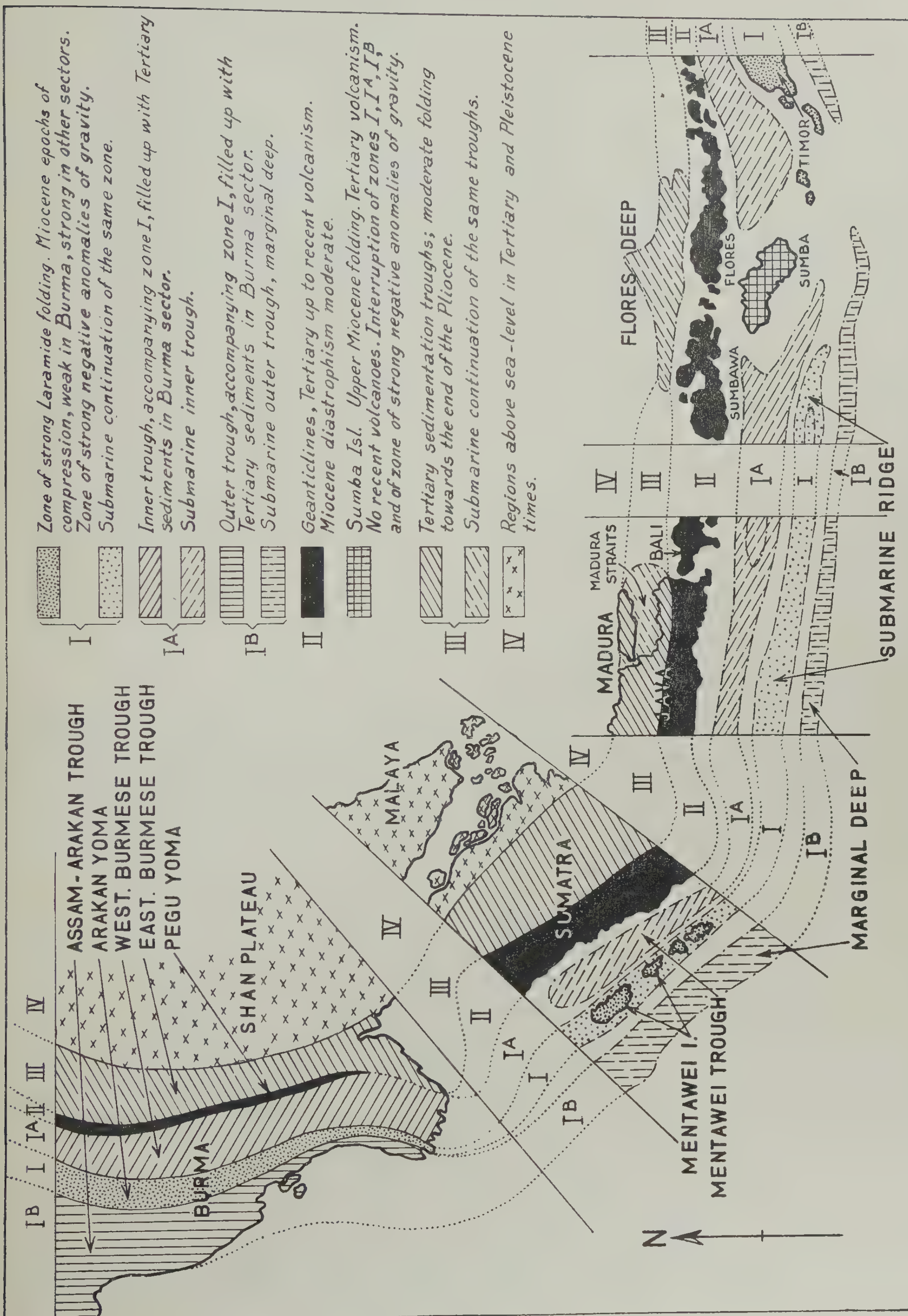

FIG. 1.—*Structural zones of the East Indies and Burma.*

during early Miocene times there was a complete separation of the Assam and Burma areas of deposition." At any rate it seems probable that a Mid-Miocene phase and a post-Pliocene phase of crustal movement can be distinguished in the Arakan Yoma.

It remains to be seen whether the mountain root which was revealed by the pronounced gravity minimum dates from the Laramide phase of compression or whether it became rejuvenated during the more recent phases of crustal movement. Regarding the East Indian belt we meet the same unsolved question. There the most recent epoch of folding of the strata appears to have taken place in the Miocene (Tertiary f_2). But the Miocene phase was followed by a Plio-Pleistocene phase of movement which is, however, characterised especially by faulting and vertical displacements. Possibly a rejuvenation of the mountain root took place during this phase " strengthening the negative anomalies which must already have been weakened to the strong negative which is still to be found " (Umbgrove *in* Vening Meinesz, 1934, p. 160).

No gravimetric data are known from the region between Burma and Sumatra. Doubtless, however, the connection between the Burmese Arakan Yoma and the islands west of Sumatra runs over the Andaman and Nicobar islands. What is known of the geological history of these islands accords very satisfactorily with this conception (Gee, 1926; Tipper, 1911; Huber and Burri, 1933).

IB. As in the East Indies, zone I is accompanied on either side by a trough. In Burma, however, the troughs are entirely filled up with sediments, ranging from Eocene to Plio-Pleistocene in age. The oil-bearing strata of the Assam-Arakan area form the contents of a trough which can be correlated with the marginal deep-sea troughs west of Nias and the Mentawei islands and south of the submarine ridge, south of Java.

1A. In a similar way the Mentawei trough has its counterpart in the sedimentation trough which runs east of the Arakan Yoma and west of the volcanic belt of central Burma.

As in the IB and III troughs sedimentation took place from Eocene until Upper Tertiary, after which a moderate folding took place.

II. Dudley Stamp (1922) constructed a map showing the paleogeographic conditions of Burma during early Tertiary times (see also Chhibber, 1934, p. 211). On this map the area between Arakan Yoma and Shan Plateau is subdivided into two separate sedimentation troughs by a narrow median ridge. The ridge coincides with a belt of Tertiary to sub-Recent volcanic rocks and volcanoes (Chhibber, 1934, p. 287). This belt can be traced towards the volcanic geanticline of West Sumatra and South Java via the volcanic islands Narcondam and Barren Island. It remains an open question why the geanticline lies much lower in Burma than in Sumatra and still lower in the intervening area.

Judging from the schematic geological profiles, published by Huber, Tertiary strata possibly were deposited over the geanticline forming an uninterrupted connection between the western and eastern Burmese troughs. The same phenomenon took place in several areas of the Sumatra sector, to a greater degree in Java, and still more in the Lesser Sunda islands.

III. The Tertiary sedimentation trough east of the volcanic belt of Central Burma is called Eastern Burmese Gulf in Stamp's paleogeographic map. It contains a sequence from Eocene to Pliocene strata. According to Cotter the present Gulf of Martaban is a continuation and remnant of this geosynclinal area. Likewise the corresponding trough in North Sumatra is clearly continued below the sea and the corresponding trough of Eastern Java into Madura Straits. Possibly the Flores deep is a similar trough though still deeper due to a smaller rate of sedimentation.

IV. The eastern Burmese trough is bounded on its eastern side by the Shan Plateau consisting of pre-Tertiary rocks which were intensely folded (Lamaride phase).

During Tertiary times land conditions prevailed in this area. We find the continuation of this Tertiary land in Malaya, Riouw Archipelago, Banka, Billiton and the western part of Borneo, including the greater part of the South China Sea and the Java Sea. These shallow seas were still land areas during part of the Pleistocene as mentioned in the previous section.

GENETIC INTERPRETATION OF THE STRUCTURAL PATTERN

According to the theory of Vening Meinesz, the earth's crust may react (under certain circumstances) by the development of large waves during epochs of increasing compression. In a downward wave sediment may accumulate giving origin to a geosyncline. The upward wave forms a rising geanticline. When the strength of the crust is surpassed it will give way at the weakest place of a downward wave. Thus a great isoclinal protuberance of the crust will become down-folded so as to form a sialic root penetrating the simatic material beneath. Fig. 2A represents this stage schematically. The sedimentary contents of the downward wave—zone I—were strongly folded and crumpled. Whether they appear as a submarine ridge or as an island festoon depends on the quantity of strata that was squeezed out and on the dimensions of the sialic root. Following upon the first buckling movement a new epoch of increasing compression caused a rejuvenation, i.e. a further downbuckling of the sialic root, part of which probably disintegrated and spread during the intervening lapse of time. The first root formation may have occurred in a very remote past.

The sialic root must have a marked tendency to rise. As soon as the strong compression in the crust decreases, the process of restoration of isostatic equilibrium begins. As a further consequence simatic material will flow towards the belt of buckling and a furrow will form on either side of the folded zone. This stage is represented by the schematic profile B of Fig. 2. Zone I corresponds to the string of islands west of Sumatra and to the Timor-Buru arc, Ib to the series of marginal deep-sea troughs, Ia to the deep-sea troughs between outer and inner arc.

Remarkably enough both the negative zone and the accompanying deep-sea furrows are interrupted, or at least, much reduced in boldness, near Sumba. This island probably stands as the exceptional evidence of a type of terrain that elsewhere subsided so as to form the bottom of one of the series of deep-sea furrows between the outer and inner arcs.

The volcanic geanticline of the inner arc is indicated by II.

The next downward wave III is represented by a series of subsiding troughs, which have been filled up by oil-bearing sediments in Sumatra and Java. These strata underwent moderate folding during a later epoch of compression. The present stage is shown in the tentative and schematic block-diagram, Fig. 3. Filling up of the trough behind the inner arc is possible only if the quantity of waste products from the surrounding areas equals or surpasses the rate of subsidence of the bottom of the trough. An example is shown in the foreground of the block. The other possibility is that the rate of subsidence of the bottom surpasses the supply of sediments. In that case a deep-sea basin will originate and persist. This case has been drawn also in the block-diagram. Possibly the Flores deep is an example.

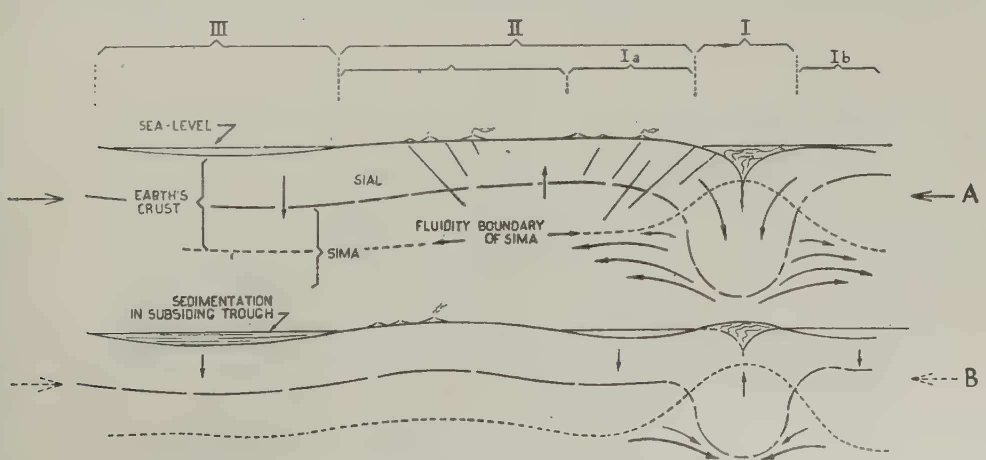

FIG. 2.—*Two schematic sections showing tentatively the development of structural zones in the East Indies.*

The different aspects of the Burmese zones IA and IB if compared to the East Indian furrows may be explained in a similar way. The Burmese troughs received more material from the surrounding areas. Hence they became oil-bearing areas of economic importance in strong contrast to the East Indian furrows.

The very strong rate of filling up of the Burmese troughs as compared to the East Indian A and B troughs finds its explanation in the different conditions of the surroundings. Sediments were transported into the Burmese troughs from three sides, viz., (1) the Shan Plateau in the east; (2) the Arakan Yoma in the west; (3) the Irrawaddy in the north.

On the other hand the marginal deep west of Sumatra and south of Java received clastic sediments from one side only, viz., from the Nias-Mentawei islands, or in the second case mentioned from Java via a submarine ridge. For the same reason the A troughs from Sumatra to Sumba are not so deep, i.e., they are filled up to higher level than the B troughs. And the Mentawei trough is in an especially favourable position in as much as it receives material from either side.

The correlation of structural zones in Burma and the East Indies confirms the conclusion already given in a former publication, that both continental and submarine troughs may be classed according to the same fundamental principles. " For whether a subsiding area appears at the surface as a depression or not depends merely on the relation between subsidence of the bottom and supply of detritus derived from the adjoining areas " (Umbgrove, 1947, p. 54 and p. 194). As a matter of fact, all the structural elements appear either above sea-level or as submarine features. This point is illustrated in Figs. 1 and 3.

To exclude submarine furrows from an attempt at classification of geosynclines, troughs and basins is an unreasonable procedure. Kay (1947, p. 1289) is right when pointing out that the original definition of a geosyncline " gives rocks as representatives." However, are not the strata accumulating in submarine furrows also rocks from a petrographic, geological and genetic point of view? Moreover nobody can deny the East Indian deep-sea furrows " to be potential sites of orogeny." This point will be clear to everyone studying their counterpart in Burma. To enter upon the question why the different sectors underwent the different structural history summarised in the above given sections would lead into realms of mere speculation. It seems preferable to wait for more geological as well as geophysical data. The latter are especially needed for the sector between Burma and Sumatra.

TIME OF ORIGIN OF THE DEEP-SEA TROUGHS OF THE EAST INDIES

Although the submarine A and B troughs of the East Indies have their counterpart in Burmese troughs in which the subsiding movement started in Eocene times, this does not necessary imply the

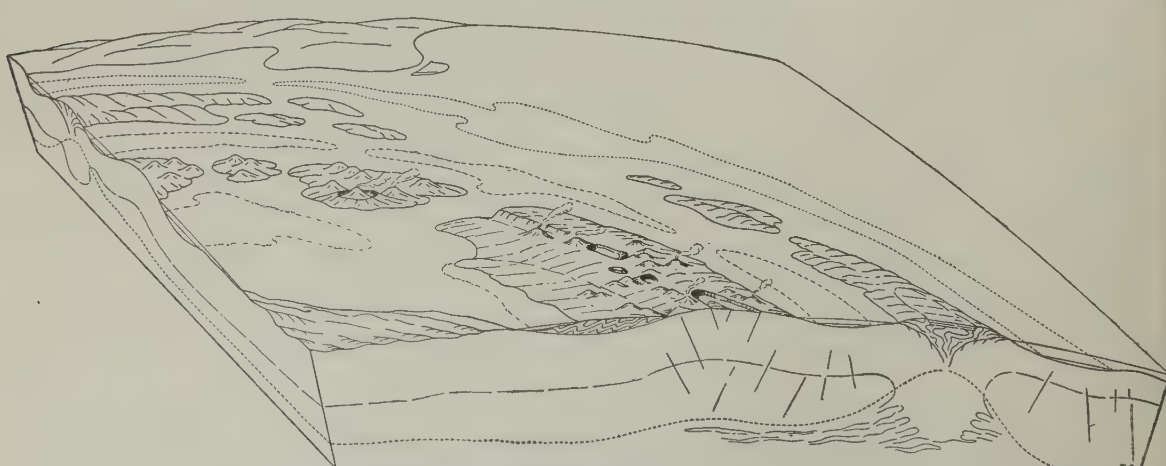

FIG. 3.—*Schematic block-diagram of the East Indies.*

same time of origin for the East Indian troughs. In this connection one need only take into consideration the time of origin of the troughs belonging to zone III. In Burma and North Sumatra they originated in the Eocene (after the Laramide epoch); in South Sumatra and Java, however, the downward movement began in the Miocene (after the Miocene epoch of folding, characterizing zones I and II).

Therefore the fact that the Burmese troughs date from the Eocene does not exclude a younger age for the East Indian deep-sea troughs. Morphological as well as geological arguments have been brought forward to substantiate the theory of a comparatively young origin of the deep-sea relief in the East Indies (Kuenen, 1935, pp. 49-50; Umbgrove, 1938, pp. 55-60, 1934 in Vening Meinesz, p. 154). Intersection of Miocene fold structures by the trend of the present coastline pointed to a post-Mid-Miocene time of origin (post-Tertiary f_2 of East Indian stratigraphy).

Moreover, if subsidence of the troughs kept pace with the elevation of the intervening ridge and islands, an important part of the movement would have taken place in post-Tertiary times.

However, this does not preclude the downward movement of the bottom beginning as early as Eocene times, though this does not necessarily mean a movement of all the troughs nor a sinking of the whole area of a present deep-sea furrow. These restrictions follow from a comparative study of the structural zones of Burma and the East Indies.

The actual course of events cannot possibly be unravelled. Even if we suppose the movement of the deep-sea troughs dates from early Tertiary times, two possible modes of origin remain open.

The main difference in the geological history of Burmese and East Indian sectors is that the East Indian IA and IB troughs have not been filled up like the Burmese troughs.

One possibility is that sedimentation in the East Indian sectors was too slow from the very beginning, so that they always have been submarine furrows though not necessarily always as deep as they are now. In that case the primary troughs must have been of smaller dimensions. For their present morphology shows all the marks of a youthful origin and geological facts show that their present boundaries originated in Miocene or more recent times.

The other possibility is that originally the East Indian troughs were filled up partly or wholly with sediments in much the same way as the Assam and Burmese troughs. In that case the subsiding movement of the troughs must have been accelerated after a more recent epoch of diastrophism, thereby gradually giving origin to deep furrows when the subsiding movement came to surpass the rate of sedimentation.

This did not happen in the Burmese sector where these troughs are now high and dry above sea-level. Possibly a rejuvenating subsidence occurred also in the Burma sector. If so, however, it must have been of less intensity when compared to the East Indies.

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DISCUSSION

A. Heim said that the Sunda Islands were the most wonderful example of present geosynclines and geanticlines. Correlation of terraces over long distances was made difficult on account of vertical movements. On several eastern islands sub-Recent coral reefs were raised many hundred metres above sea-level as at Timor. He had found numerous " living diapirs " on the arch around the trough of the Banda Sea. They were plugs of argillaceous and salty material of Jurassic and Triassic age which had pierced the Tertiary crust. The Islands were in tectonic motion (Heim: Lebenden Diapirinseln. *Eclogae Geol. Helv.* 33, 1940). Heim also said that it was of great importance in understanding the formation of geosynclinal troughs to study magnetic deviations. Though less pronounced than the island arc around the Banda sea, the lines of equal magnetic deviations showed a pronounced convex arc towards the east.

J. H. F. Umbgrove replied, saying that Dr. Visser, in the only published paper on magnetic anomalies in the East Indies, pointed out some vague relations between magnetic and gravimetric anomalies. He hoped the map which Dr. Heim saw would be published soon.

M. Kay said that Palaeozoic rocks in the borders of North America suggested the presence of ancient island arcs. Maps of the present East Indies showed a narrow belt of volcanoes, whereas volcanic rocks occupied a much broader belt at times in the American Palaeozoic. He asked whether the distribution of volcanoes in the East Indies was representative of that known in past periods.

J. H. F. Umbgrove replied that it was unfortunately not possible to construct palaeogeographic maps of the East Indies showing the distribution of volcanism in Mesozoic and Palaeozoic times.

LIST OF THE PARTS OF THE REPORT OF THE EIGHTEENTH SESSION